PB81-125296

Production of Non-Food-Chain Crops with Sewage Sludge

PEER Consultants, Inc.
Rockville, MD

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Nov 80

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/2-80-199
November 1980

PB81-125296

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by

Lilia A. Abron-Robinson
Cecil Lue-Hing
PEER Consultants, Inc.
Edward J. Martin
David W. Lake
Environmental Quality Systems, Inc.
Rockville, Maryland 20852

Contract No. 68-03-2743

Project Officer

Gerald Stern
Municipal Environmental Research Laboratory
Cincinnati, Ohio

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/ 2-80-199	2.	3. RECIPIENT'S ACCESSION NO. PB81 125296
4. TITLE AND SUBTITLE Production of Non-Food-Chain Crops with Sewage Sludge		5. REPORT DATE November 1980
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Lilia A. Abron-Robinson, Cecil Lue-Hing, Edward J. Martin, David Lake		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS PEER Consultants, Inc. & Environmental Quality Systems Inc. 1160 Rockville Pike, Suite 202 Rockville, Maryland 20852		10. PROGRAM ELEMENT NO. 36B1C, D.U. B/121, Task C/38
		11. CONTRACT/GRANT NO. 68-03-2743
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory --Cin., OH. Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Research & Development
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Gerald Stern (513) 684-7654

16. ABSTRACT

Feasibility and market potential were determined for non-food-chain crops cultivated using sewage sludge.

Non-food-chain crops that are currently being sold on the open market or that have a good potential for marketability were selected. From a list of 20 crops, 3 were selected and subjected to a cost analysis to determine how the costs for cultivation using sewage sludge compared with the costs for cultivation using commercial fertilizer.

Cotton, sod, and energy biomass trees were determined to have the best potential for cultivation using sewage sludge, based on the market values and nutrient requirements for each crop, and on the hectares presently under cultivation for production of these crops.

Results indicate that large quantities of sewage sludge can be used, based solely on the nitrogen and phosphorus requirements for the cultivation of these crops. In addition, it was determined that although the total costs for fertilization using commercial fertilizer are less than the costs for using sewage sludge, the latter would be viewed more favorably if the costs were borne by the municipality generating the sludge.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sludge, Sludge disposal, Cost comparison, Cost effectiveness, Cost estimates, Feasibility, Marketing value	Non-food-chain crops, Marketing potential, Sewage sludge, Comparison with commercial fertilizer	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The utilization of sewage sludge as a resource has been proposed by the U.S. Environmental Protection Agency. In this regard, this study examines the feasibility and market potential for the production of non-food-chain crops with sewage sludge.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory

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ABSTRACT

Feasibility and market potential were determined for non-food-chain crops cultivated using sewage sludge.

Non-food-chain crops that are currently being sold on the open market or that have a good potential for marketability were selected. From a list of 20 crops, 3 were selected and subjected to a cost analysis to determine how the costs for cultivation using sewage sludge compared with the costs for cultivation using commercial fertilizer.

Cotton, sod, and energy biomass trees were determined to have the best potential for cultivation using sewage sludge, based on the market values and nutrient requirements for each crop, and on the hectares presently under cultivation for production of these crops.

Results indicate that large quantities of sewage sludge can be used, based solely on the nitrogen and phosphorus requirements for the cultivation of these crops. In addition, it was determined that although the total costs for fertilization using commercial fertilizer are less than the costs for using sewage sludge, the latter would be viewed more favorably if the costs were borne by the municipality generating the sludge.

This report was submitted in fulfillment of Contract No. 68-03-2743 by PEER Consultants, Inc. and Environmental Quality Systems, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1, 1978 to December 1979, and work was completed as of May 1980.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

Btu -- British thermal unit
CAST -- Council for Agricultural Science and Technology
cm -- centimeter
d -- day
DMTE -- dry metric ton equivalent
DMT -- dry metric ton
DT -- dry ton
ft -- feet
ft^2 -- square feet
ft^3 -- cubic feet
gal -- gallon
ha -- hectare(s)
hp -- horsepower
J -- joule
Kcal -- kilocalories
Kg -- kilogram
kJ -- kilojoule
kl -- kiloliter
KW -- Kilowatt
l -- liter
LA/OMA -- Los Angeles/Orange County Metropolitan Area
lb -- pound
M -- meter
M^2 -- square meter
M^3 -- cubic meter
mil -- million
ml -- milliliter
mm -- millimeter
MOP -- Manual of Practice
MSC -- Milwaukee Sewage Commission
MSDGC -- Metropolitan Sanitary District of Greater Chicago
MT -- metric ton
NFCC -- non-food-chain crop(s)
POTW -- publicly owned treatment works
SIC -- Standard Industrial Classification
WAO -- wet air oxidation
WPCF -- Water Pollution Control Federation
yr -- year

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ABBREVIATIONS AND SYMBOLS (continued)

SYMBOLS

K -- potassium
K_2O -- potassium oxide
N -- nitrogen
NH_3 -- ammonia
NPK -- nitrogen, phosphorus, potassium ratio
P -- phosphorus
P_2O_5 -- phosphorus pentoxide
% -- percent

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ACKNOWLEDGMENTS

The assistance of the many Federal agencies and private corporations and businesses is gratefully acknowledged. Also, the cooperation and overall project coordination by Mr. Gerald Stern (EPA Municipal Environmental Research Laboratory, Cincinnati, Ohio) as the Project Officer is appreciated.

The project investigators wish to express their appreciation to Ms. Beverly Preston, Ms. Sharon Fried, and Ms. Susan Orye who spent many hours on the manuscript preparation. The project investigators are also indebted to their colleagues for their assistance and suggestions during the development of the information presented in this report.

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SECTION 1

INTRODUCTION

BACKGROUND

About a quarter of the stabilized sewage sludge produced by publicly owned treatment works (POTW) in the United States is disposed of directly to the soil. Increasing restrictions on alternative sewage disposal practices and increased sludge production because of implementation of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) will result in greatly increased quantities of sewage sludge being applied to the land. Furthermore, it is a valuable resource because of its nutrient and organic content, and increasing emphasis will be placed on beneficial uses of sewage sludge simultaneously with land disposal practices for sewage sludge. The prospects of widespread land application of sludge, however, have caused increased concern over possible accumulation of toxic substances (e.g., heavy metals, pesticides and other organics, and pathogens) in soils. The translocation of these toxic substances to growing crops, fodder used in silage, and to pastures is poorly understood. Even less information is available on the translocation of these toxic substances throughout the direct food chain to animals and humans. Another approach, then, is to use sewage sludge for the cultivation of non-food-chain crops (NFCC). This beneficial use of the sludge could perhaps circumvent the problems associated with the unknown impacts of the toxic materials in the sludge on the food chain.

The literature is replete with documented experiences on the application of sewage sludge to agricultural land, and there are some studies involving the reclamation of disturbed lands (e.g., strip mine areas) with sewage sludge. The data base for guidance concerning application of sewage sludge to land comes from these studies. Pietz et al. (1) and the U.S. Department of Agriculture (USDA) (2), as well as many others, have shown that it is technically and economically feasible to land spread sewage sludge on agricultural and disturbed land. Therefore, it is worth considering the possibility that the production of NFCC is also technically and economically feasible. If this were found to be true, perhaps it would be possible to permit large-scale applications of sewage sludge to the land for beneficial purposes without the concern of increasing levels of toxics in the human food chain.

Objectives

The primary objectives of this study were to evaluate the feasibility and market potential for land application of sewage sludge for the cultivation of NFCC.

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SECTION 2

CONCLUSIONS

The following conclusions have been made as a result of this study:

1. The non-food-chain crops (NFCC) with the best apparent feasibility for production using sewage sludge are:

    1. Softwoods amenable to monoculture operations
    2. Forest nurseries
    3. Horticultural specialties
    4. Energy biomass trees
    5. Oil crops such as cotton and soybeans

Though cotton and soybeans do not fit the definition of NFCC, it was felt that the inedible products from these crops were sufficient to warrant their inclusion in this report.

2. Based on the criteria developed for this study, sod, cotton, and energy biomass trees were selected as having the best apparent feasibility and market potential.

3. Of the three crops considered, utilization of sludge for sod production is the most feasible at this time. Sod production would use, conservatively, 5% to 10% of the total sludge generated in the sod producing states.

4. Based on only the three crops presented here, at least 20% of the total sludge generated could be used for growing NFCC.

5. The variations in cost for sludge application among geographic regions in the United States for the three crops examined are small compared to variations based on the method of application and crop type.

6. The costs of sludge application to biomass trees and in some cases cotton using the truck-spreading option compare favorably to the costs for commercial fertilizer.

7. Transport costs for sludge can range from 1.5 to 7 times the cost of sludge application for the cases studied based on a one-way transport distance of up to sixty (60) miles transporting liquid sludge and sludge cake. Transport costs vary between about $27/dry metric ton (DMT) ($25/dry ton (DT)) for sludge cake to $110/DMT ($100/DT) for liquid sludge.

8. Using sewage sludge for the production of NFCC could be the least costly alternative for sludge disposal by a POTW, particularly if a cost benefit is derived by also recovering damaged or upgrading non-productive land to produce the NFFC.

9. To promote the use of sewage sludge for the production of NFCC, most of the costs (transportation and application) associated with the use of this material should be borne by the municipality generating the material.

SECTION 3

RECOMMENDATIONS

1. Research centered on the production of new and unusual crops such as the jojoba, euphorbia, and guayule should include the use of sewage sludge as a source of nutrients or as a growing medium.

2. Non-food-chain uses for cotton and soybeans are great, and these crops have high N requirements. Thus a management system should be developed to permit the use of sewage sludge for the cultivation of a portion of those crops on a national basis. This management system would insure that those crops would not be used for food-chain products.

3. The costs for sludge application to NFCC should be studied in detail to bring the comparison with commercial fertilizer into sharp focus. Good cost estimates will assist in making the decision to use sludge on NFCC as an alternative to commercial fertilizer or to enhance growth conditions.

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SECTION 4

FERTILIZER AND ENERGY VALUE OF MUNICIPAL SEWAGE SLUDGE

INTRODUCTION

The most common disposal technologies in use for POTW sludges are not based on the fact that this material is a recoverable resource, but that it is a spent resource with no further value. However, new technologies are being developed which emphasize reuse of the minerals and organic matter present in POTW sludges. As with any new technology, the benefits and drawbacks of the technology must be carefully studied in order to make a determination of worth. It has been demonstrated many times that the nutrient content of POTW sludges can be used for crop production, and it has been suggested that these nutrients be used to supplement that provided by chemical fertilization. The sludge also has soil conditioner value. This suggestion has merit especially when the costs of production of the nutrients are compared.

If POTW sludges can be used for plant production by supplying the adequate nutrients necessary for growth, then the availability of this material should be known and estimates of its nutrient value should also be known. In addition, the value (both as a nutrient supplier and the economics of production and application) of this material should be compared with the value of the primary material most commonly in use. Once the above facts are known, then the user is in a better position to determine the preferred product for use.

This section gives an estimate of the quantities and nutrient value of POTW sludges. Also, the quantities of chemical fertilizers that must be produced to supply the plant nutrients present in POTW sludges were calculated for purposes of looking at the energy costs involved. Lastly, the amount of energy required to chemically produce the nutrients contained in POTW sludges was compared with the energy required to incinerate (destroy) these sludges. This was done to explicitly show possible energy savings when beneficial POTW sludge usages are considered. This information puts in perspective the nutrient value of POTW sludge in relation to equivalent amounts of chemical fertilizer, the energy needed to produce an equivalent amount of chemical fertilizer and the amount of energy needed to destroy the sludge. Energy costs are discussed below.

QUANTITY OF SEWAGE SLUDGE GENERATED BY POTW'S

National sludge production figures are difficult to estimate, but there are many estimates given in the scientific literature. Dean (3) estimated the actual national sludge production in 1972 to be approximately 9,072 DMT/d (10,000 DT/d) and by 1990 the estimated quantity would be nearly 11,794 DMT/d (13,000 DT/d). The Council for Agricultural Science and Technology (CAST) (4)

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estimated municipal sludge production to be 8,115 DMT/d (8,945 DT/d) for 1970 and that this would increase to 16,456 DMT/d (18,140 DT/d) by 1985. Thus, there are considerable differences in the quantities of municipal sludge as estimated by Dean and CAST.

The Water Resources Council (5) estimated that the sewered population in 1970 was 135 million (mil), while for 1985, 176 mil is projected. The estimate was based on the U.S. population being served by sewers as 67% in 1970 and 75% in 1985. Farrell (6) estimated that the per capita daily raw sludge production was 0.055 Kg (0.12 lb) for primary plants and 0.091 Kg (0.20 lb) for primary and secondary plants. The degree of treatment obviously impacted sludge production.

If it is assumed that in 1970, 50% of the U.S. sewered population was served only by primary and secondary plants and that the other 50% was served by primary plants, then the annual sludge production would be 9,843 DMT/d (10,850 DT/d). For 1985, assuming that all municipal plants had primary and secondary treatment, the annual sludge production would rise to 16,012 DMT/d (17,650 DT/d). The sludge production estimates used for these senarios are reasonable when compared with the estimates given by Farrell and CAST.

PLANT NUTRIENTS IN SEWAGE SLUDGE

Municipal sludge is derived from the organic and inorganic matter removed from wastewater at sewage treatment plants. The amounts of the constituents present will depend upon the wastewater sources and the method of wastewater and sludge treatment.

Municipal sludge contains significant amounts of N, P, and K as well as other plant nutrients. Table 1 shows the data of Zenz *et al.* (7) and Sommers *et al.* (8). Zenz *et al.* (7) collected samples from 24 plants in the state of

TABLE 1. MAJOR PLANT NUTRIENTS PRESENT IN VARIOUS SEWAGE SLUDGE SOURCES, PERCENT DRY WEIGHT

Constituent	Illinois-24 cities (7)		7 States in the U.S. (8)	
	Range	Mean	Range	Mean
Total N	2.6-9.8	5.4	.03 - 17.6	3.2
Ammonia Nitrogen	0.1-6.1	1.8	.0005 - 6.7	0.7
P	0.7-4.9	2.4	.04 - 6.1	1.8
K	--	--	.008 - 1.9	0.3

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Illinois, while Sommers et al. (8) collected samples from plants in Wisconsin, Minnesota, Michigan, Ohio, New Jersey and New Hampshire. Sommers et al. (8) collected over 180 samples for the N, P, and K data given in Table 1. As can be seen, municipal sludge is a good source of N, P, and K, the major plant nutrients. The data collected by both Zenz et al. (7) and Sommers et al. (8) was for a variety of sludges from various wastewater and sludge treatment processes. In general, municipal sludges have a total N content of 1% to 6% which is partly in the inorganic form and partly in the organic form (9, 10). Generally, 30% to 60% of the total nitrogen in anaerobically digested sludge is present as ammonia nitrogen while the remainder is organic nitrogen (11). Phosphorus in sewage sludge, as shown by the data of Zenz and Sommers ranges from about 1% to 6%. The P in sewage sludge is generally considered to be as available to plants as the P in chemical fertilizers (12). Potassium, as shown in the data from Sommers, ranges from about 0.04% to 6.1%, but the mean is 1.8%. Because of the low levels of K in municipal sludge, it is generally not considered a good source of this nutrient.

Plant Nutrient Levels in Various Sludges

As noted above, the data of Sommers and Zenz represented a broad spectrum of various wastewater and sludge treatment processes. As such, the data show the national picture of the nutrient content of municipal sludge. However, the nutrient content will vary with the types of sludges which are produced by the various sewage and sludge treatment processes. Although limited data are available, they are sufficient to indicate the relative levels of the plant nutrients available.

Sommers (13) reported data on the N, P, and K levels of sludges from POTW's using anaerobic digestion and aerobic digestion. These levels are given in Table 2. As would be expected, the mode of digestion makes little difference in the total levels of N, P and K, though the chemical state of the nutrients do vary.

TABLE 2. N, P, AND K LEVELS IN ANAEROBIC AND AEROBIC DIGESTED SLUDGES

	Type of sludge	
Nutrient (%)	Anaerobic	Aerobic
N	4.2	4.8
P	3.0	2.7
K	0.3	0.4

Sommers et al. (14) also studied the effect of the wet air oxidation (WAO) process on sewage sludge composition. Data were compiled on the plants before and after treatment. The data are presented in Table 3. As can be seen, the WAO

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process significantly reduced the soluble and particulate N. This would be expected since ammonia nitrogen is sensitive to heat and will volatilize.

TABLE 3. NUTRIENT CONTENT OF SEWAGE SLUDGE BEFORE AND AFTER WET AIR OXIDATION (14)

Constituent (%)	Before WAO	After WAO
Soluble P	0.082	0.004
Particulate P	1.07	1.21
Soluble Total N	1.35	0.47
Soluble Organic N	0.293	0.173
Particulate Total N	2.12	0.85
Particulate Organic N	1.83	0.86

Lagooning of sludge also reduces the N content due to ammonia volatilization and supernatant drawoff. Peterson et al. (15) compared the total N of fresh digested sludge with that of sludge from lagoons having supernatant drawoff. The data are given in Table 4.

TABLE 4. IMPACT OF LAGOONING ON THE NITROGEN CONTENT OF SLUDGE

Constituent (%)	Digested sludge	Lagooned
Total N	7.27	2.60
Ammonia Nitrogen	3.26	1.20

Heat drying will also cause a decrease in sludge ammonia nitrogen due to volatilization. Peterson et al. (15) compared the level of total N and ammonia nitrogen in sludge before and after heat drying. The data are given in Table 5. Although total N remained unchanged, virtually all of the ammonia nitrogen was volatilized by the heat drying process.

TABLE 5. NITROGEN CONTENT OF SLUDGE BEFORE AND AFTER HEAT DRYING

Constituent (%)	Before	After
Total N	6.7	6.4
Ammonia Nitrogen	0.4	trace

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Primary sludges appear to have characteristics similar to those noted above for the sludges studied by Sommers et al. (8). Manual of Practice No. 8 (MOP) of the Water Pollution Control Federation (WPCF) gives the values of N, P, and K for primary sludges as shown in Table 6 (16). Waste-activated sludge appears to have a somewhat higher N and P content than primary sludges. This is expected because activated sludge microorganisms utilize these constituents in significant quantities. Anderson (17) summarized waste-activated sludge data from both the Metropolitan Sanitary District of Greater Chicago (MSDGC) and the Milwaukee Sewage Commission (MSC). The data are given in Table 7.

TABLE 6. N, P, AND K VALUES FOR PRIMARY SLUDGES

Constituent (%)	Range	Typical value
Total N	1.5 - 4.0	2.5
Total P	0.35- 1.22	0.69
Total K	0.0 - 0.83	0.29

TABLE 7. NUTRIENT CONTENT OF TWO WASTE-ACTIVATED SLUDGES

	Waste-activated Sludge	
Constituents (%)	MSDGC	MSC
Total N	5.6	6.0
Total P	3.05	1.74
Total K	0.46	0.34

There is not an extensive amount of data available on the nutrient content of trickling filter sludge and what is available is rather old. However, Vesilind (18) reported that the N and P content of trickling filter sludge was 2.9% and 1.2%, respectively. This would indicate that the N and P content of trickling filter sludge is relatively low when compared to that for waste activated sludge.

Dewatering of sludges can result in changes in the nutrient content of sludges. This occurs due to the removal of soluble components in the supernatant, principally ammonia nitrogen, and in the case of vacuum filtration using lime, by volatilization of ammonia gas. However, it is difficult to generalize about the exact effect in any particuliar case. Zenz et al. (19) gives data on the N, P, and K content of dewatered sludges from anaerobic digesters using a centrifuge, a vacuum filter and belt filter press. The data are given in Table 8. In general, the P and K content for all 3 units studied were similiar. This was expected because those nutrients are not very soluble in digested sludges and should not be affected even if the relative captures of the various dewatering techniques were somewhat different. The vacuum filtered sludge had the lowest N concentration in its cake. This was probably due to the lime addition and the resulting ammonia volatilization.

TABLE 8. NUTRIENT CONTENT OF VARIOUS DEWATERED SLUDGES

Constituent %	Centrifuge Avg.	Centrifuge Range	Vacuum filter Avg.	Vacuum filter Range	Belt filter press Avg.	Belt filter press Range
Total N	3.25	2.47 - 4.15	2.8	0.71 - 3.13	3.1	2.2 - 3.8
Total P	1.84	0.71 - 3.13	1.6	1.2 - 1.7	1.6	1.2 - 1.7
Total K	0.19	0.15 - 0.21	0.12	0.7 - 2.3	0.21	0.14 - 34

Value of the Nutrients in Municipal Sewage Sludge

It is obvious from the above that municipal sewage sludge has significant levels of N, P, and K which can be used for fertilizing crops. In this section the amounts of N, P, and K contained in sewage sludge equivalent to that in chemical fertilizers are computed and cost estimates for the sludge nutrients are made based on current fertilier market prices for the nutrients. Costs for N, P, and K were obtained from the International Mineral and Chemical Company (20) as posted for January 21, 1980. The prices of inorganic N, P, and K were \$0.253/Kg (\$0.115/lb), \$1.37/Kg (\$0.621/lb), and \$0.259/Kg (\$0.1176/lb), respectively.

As previously discussed, Sommers et al. (8) found that the mean N, P, and K in seven states of the U.S. was 3.2%, 1.8% and 0.3%, respectively. It was also noted that a good estimate of U.S. sludge production for the years 1970 and 1985 is 9,843 DMT/d (10,850 DT/d) and 16,012 DMT/d (17,650 DT/d), respectively. Using these data and costs for chemical fertilizer (20), Table 9 was constructed. The figures given are for daily sludge production. As can be seen, the total daily sludge production in the U.S., based on 1980 dollars, has a chemical fertilizer equivalent market value of \$537,000 for the year

TABLE 9. DAILY VALUE AND COSTS* OF NUTRIENTS CONTAINED IN MUNICIPAL SLUDGE

Year	MT of N/d	Cost of N (\$/d)	MT of P/d	Cost of P (\$/d)	MT of K/d	Cost of K (\$/d)
1970	315	79,695	177	242,490	29	7,511
1985	512	129,536	288	394,560	48	12,432

* Cost figures were derived using equivalent commercial fertilizer nutrient values.

1985. Of course, municipal sewage sludge has benefits other than its nutrient value. The organic matter present, for example, offers many benefits including improvement in tilth and water holding capacity for sandy soils. However, it is difficult to place a dollar value on sludge benefits other than its N, P, and K value.

ENERGY REQUIREMENTS

Energy Required To Produce Nitrogen, Phosphorus and Potassium

The production of nearly all inorganic nitrogen fertilizers requires energy. To produce inorganic N, N is combined with hydrogen under high temperatures and pressures. The initial product is anhydrous ammonia which can be used directly or converted to other forms of N such as ammonium nitrate. Most of the hydrogen is obtained from natural gas, although other possible sources are oil and coal. Obviously energy is also required for heat and to operate the equipment used in the manufacturing process.

The production of 0.9 MT (1 ton) of ammonia usually requires about 1,080 M^3 (38,140 ft^3) of natural gas of which 630 M^3 (22,248 ft^3) is used as a source of hydrogen and the remainder as a source of heat in the process (21). In addition, 34 l (9 gal) of fuel oil and 54 KW (72 hp) of electricity are usually used (21). The total energy requirement is 47.41×10^6 kJ/MT (10.27×10^6 Kcal/ton) of ammonia produced or 47,368 kJ/Kg (5,138 Kcals/lb) of N produced (21). The conversion of ammonia to other nitrogen products requires additional energy.

As noted in Table 9, the daily amount of N available in municipal sewage sludge was estimated to be 315 metric tons (347 tons) for 1970 and 512 metric tons (564 tons) for 1985. This information, coupled with the fact that 3.8 l (1 gal) of No. 4 fuel oil contains 152,408 kJ (144,452 Btu's) of energy and that the January, 1980 cost (22) of this fuel oil was about $0.24/liter ($0.91/gal), was used to generate the data given in Table 10. The estimates for the year 1985 were made using the current fuel costs, since fuel costs are too dynamic to estimate what they would be in 1985.

TABLE 10. COMPARISONS OF ENERGY REQUIREMENTS FOR THE PRODUCTION OF INORGANIC NITROGEN

Year	N in municipal sludge (MT/d)	Energy to produce equivalent ammonia nitrogen (KJ/d)	Quantity of No. 4 fuel oil to produce ammonia nitrogen (l/d)	Cost of No. 4 fuel oil	
				$/MT of N	$/d
1970	315	14.9×10^9	371,503	283.05	89,161
1985	512	24.3×10^9	605,873	284.00	145,410

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Unlike N, P is not manufactured but is mined from deposits of naturally occuring rock phosphate. Therefore, there is no energy per se required to produce it except for the considerable energy required for mining and refining. The Mining Congress Journal reported that the total energy required to produce 0.91 MT (1 ton) of elemental P is 182×10^6 kJ (172×10^6 Btu's) (23). With this information and the data on concentrations of P in municipal sludge given in Table 9, the data shown in Table 11 were compiled.

TABLE 11. COMPARISONS OF ENERGY REQUIREMENTS FOR THE PRODUCTION OF INORGANIC PHOSPHORUS

Year	P in municipal sludge (MT/d)	Energy to produce equivalent P (KJ/d)	Quantity of No. 4 fuel oil to produce P (l/d)	Cost of No. 4 fuel oil $/MT of P	Cost of No. 4 fuel oil $/d
1970	177	35.4×10^9	882,631	1,197	211,831
1985	288	57.6×10^9	1,436,145	1,197	344,675

Potassium is mined from naturally occuring potash deposits. Energy figures for the mining and refining of K_2O were not available. However, Heichel (24) reported that the "energy required for potash production is 40% to 60% of the retail value of K_2O". Therefore, although exact values were not available for K_2O production energy requirements, approximately half the retail value of inorganic K_2O can be assumed to be the cost of energy. Thus, the data given in Table 12 were developed using 50% of cost values for inorganic K given in Table 9.

TABLE 12. COMPARISONS OF ENERGY REQUIREMENTS FOR THE PRODUCTION OF INORGANIC POTASSIUM

Year	Metric tons of K/day	Total retail value ($/d)	Energy cost ($/d)	Equivalent quantity of No. 4 fuel oil required (l/d)
1970	29	7,511	3,755	15,646
1985	48	12,432	6,216	25,900

Energy Required To Incinerate Municipal Sewage Sludge

Sewage sludge incineration has been practiced for many years and essentially evolved from industrial technology developed during the 19th century. It was an extremely attractive alternative during the earlier periods of available cheap energy and minimal air pollution control requirements.

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However, due to the need for expensive air pollution control devices, the need for large quantities of auxiliary fuel to evaporate excess water, and the national energy crisis, the future for this sludge treatment process is bleak.

The objective of an incineration system is to release heat from a fuel (in this case municipal sludge) and to completely destroy all the volatile elements. Sewage sludge is difficult to combust, because it is not homogenous and it contains large quantities of water. Although the fuel content of sludge is fairly high, 11,656 to 23,312 kJ/Kg dry solids (5,016 to 10,032 Btu/ lb dry solids), the water content of most sludges requires the addition of auxiliary fuel to maintain combustion (25).

Olexsey and Farrell (26) did a survey of auxiliary fuel consumption for seven cities using sludge incineration in the United States with a total capacity of 384 MT/d (423 DT/d). The average auxiliary fuel consumption of No. 2 fuel oil was 215 l/MT (51.6 gal/DT). For this report, this figure was rounded to 200 l/MT (50 gal/ton) for a nationwide average. For purposes of comparison, it was assumed that all of the municipal sludge produced in the United States was incinerated. Based on the national sludge production as given previously, and converting No. 2 fuel oil to an equivalent amount of No. 4 fuel oil, the energy requirements and costs for sludge incineration on a national basis might be as given in Table 13.

TABLE 13. ENERGY REQUIREMENTS AND COSTS FOR TOTAL MUNICIPAL SLUDGE INCINERATION

	Total quantity municipal sludge incinerated in U.S.	No. 2 fuel oil* requirements			Equivalent No. 4 fuel oil requirements		
Year	(MT/d)	(KL/d)	($/MT)	($/d)	(KL/d)	($/MT)	$/d
1970	9,843	1,969	48.69	479,256	1,998	48.72	479,551
1985	16,012	3,202	48.67	779,304	3,250	48.71	779,945

* No. 2 fuel oil has a heating value of 40,834 kJ/l (146,500 Btu/gal).

SUMMARY

The daily costs for producing equivalent chemical fertilizer nutrients from sewage sludge can be compared to the costs required to incinerate the sludges by comparing the sum of the values presented in Tables 10, 11 and 12 with the values presented in Table 13. This comparison indicates that the daily costs for producing equivalent chemical fertilizer nutrients from sewage sludge are less than that required to incinerate the sludges. Furthermore, it seems that the destruction of the sludges is an unwise allocation of a resource. The energy requirements needed to produce inorganic N, P, and K and to destroy a source of N, P, and K are staggering. It

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is imperative that the scientific community seriously consider all resources involved and that recommendations for beneficial resource allocations be made. Energy is scarce and it is imperative that energy conservation be paramount in the decison-making process for all new and emerging technologies.

SECTION 5

METHODOLOGY FOR SELECTION OF NON-FOOD-CHAIN CROPS

Food-chain crops are defined as (1) tobacco, (2) crops grown for human consumption and (3) pasture, forage, and feed grain for animals whose products are consumed by humans. Non-food-chain crops are, therefore, those crops that remain. Thus NFCC in the strictest sense are those crops that are not directly or indirectly consumed by humans.

This definition overlooks the possibility that at some time the land may be used for the cultivation of food-chain crops. In that event, the same criteria applicable to food-chain crops with respect to soil residues may also apply to NFCC. This definition also disregards the entire concept of the food web. Some crops could be grown for NFCC purposes, but due to uncontrollable factors could be consumed in part by animals and/or fowl that may later be consumed by man. For example, soybeans could be grown for non-food purposes, but be consumed in part by foraging deer; these animals may then become food for man. However, it is necessary that information in this area be developed for use in the decision-making process.

Non-food-chain crops were selected based on the stated definition. These crops were first identified by general category using the Standard Industrial Classification (SIC) code (27). The code, however, did not include crops such as sisal, jute, and hemp. These were added to this list of NFCC because they clearly met the definition criteria, they require N and P for growth, and they have a market potential. New crops that will have a market potential but are still presently in the research stage (jojoba, euphorbia, guayule, and biomass crops, for example) were added to the list. The possibility does exist that these crops could obtain the necessary nutrients and essential elements from sewage sludge for growth. A review of this list showed that there were many potential NFCC that could be cultivated using sewage sludge as a source of nutrients. Two food crops, cotton and soybeans, were added to list. These crops were included for the following reasons: (a) data available indicated that the inedible uses of these crops could be significant enough to warrant further study; and (b) cotton clearly has a high N demand. In addition, both crops respond favorably to commercial fertilization. The selected crop categories and SIC codes are given in Table 14.

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TABLE 14. CATEGORIES OF NON-FOOD-CHAIN CROPS SELECTED FOR STUDY

SIC Group no.	SIC Industry no.	
081	0811	Timber tracts: Timber tracts and tree farms (tree plantations)
082	0821	Forest nurseries, tree seed gathering, extracting and setting
011	0119	Flax, flaxseed farms
018	0181	Horticulture specialities: Ornamental floriculture and nursery products
XXX	XXXX	Hemp, Jute, Sisal
XXX	XXXX	Miscellaneous (research crops) a. jojoba b. guayule c. euphorbia d. energy biomass (woods and herbs)
013	0131	Cotton
011	0116	Soybeans

The selection of the most feasible NFCC suitable for cultivation using sewage sludge, used for this study, was based on a developed set of criteria. Liquid digested sludge, dewatered sludge and composted sludge are included in the term "sewage sludge", unless otherwise noted. The criteria used are given below.

1. Verification of crop as a non-food-chain crop.
2. High market potential, present and future.
3. Suitability for sludge application for crop cultivation.
4. Fertilizer requirements of the crop.

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5. Sensitivity to environmental factors:

   - Hardy
   - Climate tolerance
   - pH tolerance
   - Tolerance to metals
   - Tolerance to other sludge components

6. Minerals and metals needed for growth and productivity.

7. Additional amendments to sludge required for crop cultivation.

8. Crop rotation period and efficiency of crops for utilizing nutrients in the sludge.

9. Economic crop size, acreage presently under cultivation, minimum amount of sludge needed to support growth.

10. Documented research on the crop using sewage sludge for cultivation of the crop; availability of data on growth and nutrients.

11. Proximity of the crop cultivation centers to sludge generation centers.

12. Potential of sludge application to produce an imbalance in the ecosystem.

13. Dedication of land to permanent growth of NFCC.

The most important criteria for this study were:

1. The crops must not produce edible matter that could easily become a part of man's food chain.

2. The crop must have a demonstrated or a high probability of future market potential.

3. The land used to raise the crop must have a high probability of being used continuously and exclusively for the production of that crop.

4. Data must be available that give the response of the crop to sewage sludge, or sufficient data must be available for similar crops to allow probable response determination using data extrapolation and inference.

Twenty crops were initially studied using the above criteria. These crops are given in Table 15.

TABLE 15. POSSIBLE NON-FOOD-CHAIN CROPS AMENABLE TO CULTIVATION USING SEWAGE SLUDGE

Crop category	Representative crops
Timber Tracts	Hardwoods: Aspen Sycamore Oak Sweetgum Cottonwood Softwoods: Pine varieties Douglas fir Spruce
Forest Nurseries	Those hardwoods and softwoods capable of propagation by seedlings.
Flax, flaxseed farms	Flax
Horticulture Specialties	Greenhouse varieties Shrubs Sod, turf grasses Lawn grasses
Research Crops	Jojoba Guayule Euphorbia Energy biomass (wood and herbs)
Oil Crops	Cotton Soybeans

The list of crops given in Table 15 was then reduced to six crops (or crop categories) using the selection criteria. Those six crops appeared to be the most promising non-food-chain crops. Of those six crops, three were selected for an in-depth case study.

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SECTION 6

NON-FOOD-CHAIN CROPS AMENABLE TO CULTIVATION USING SEWAGE SLUDGE

DISCUSSION OF POTENTIAL CROPS

Timber Tracts

Commercial timber consists primarily of pulpwood and sawtimber of various species. The principal sawtimber species of the U.S. are the Douglas fir and the ponderosa pine. Based strictly on inherent productivity, over 98% of the forest area in the northeast is capable of growing useable crops of timber, and over half of all commercial timberlands are occupied by eastern hardwood forest types. Softwood types make up approximately 42%, western hardwoods approximately 3%, and nonstocked (cleared) areas approximately 4% of the commercial timberlands. Approximately 202 x 10^6 ha (500 mil acres) of land in the U.S. are devoted to commercial timber tracts, with 40.5 x 10^6 ha (100 mil acres) being located in the National Forests (28).

Sewage sludge could be useful as a source of nutrients and as a soil conditioner in situations where:

1. The establishment of tree plantations is desired.
2. The reforestation of clear-cut areas or forest fire devastated areas is desired.
3. The production of seedlings is desired.

Tree plantations for commercial use are for the most part monocultures, and thus could possibly serve as buffers to the movement of sludge contaminants into the surrounding ecosystems and food webs. "Monocultures", the growth of one species of plants to the exclusion of others, provide very little variation of habitat or food as is required for healthy (balanced) ecosystems. Therefore, the utilization of these monocultures for food by "wild" populations of animals or fowl may be restricted resulting in little effect upon surrounding ecosystems. These plantations tend to be located in areas that are accessible by truck or pipeline for sludge transport. Also, they are located mainly in regions where production of the crop is rapid, such as the southeastern U.S. Examples of tree crops grown in plantations are the pine, spruce and fir trees for the production of pulp and paper and for Christmas trees.

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Tree crops used for pulp and paper are normally fertilized only once at the time of planting, and have a rotation period of 10 to 20 years. The faster growing varieties with a rotation period of less than 20 years require intensive cultivation and are not currently being used to any great extent by industry because of growing costs. It is not a common practice to fertilize Christmas trees since fertilization causes rapid growth and "leggy" trees. Labor costs for pruning would outweigh benefits of quicker growth to saleable size.

The nutrient requirements of forest trees are less well known than those of agricultural crops. Forests are usually fertilized naturally, but the external addition of nutrients and moisture can stimulate tree growth. The external addition of nutrients and moisture could be economically beneficial where poor soils exist. Generally, tree fertilization has been confined to nurseries and orchards. The cost of fertilizing a forest could be expensive and difficult to achieve due to inaccessibility of the sites; however, fertilization by air is feasible. (Of course, this practice would preclude the possibility of using sewage effluent or sewage sludge.) It has been suggested that a forest be fertilized about once every five years, thereby increasing yields by as much as 20% (29). It is not known if this increased volume of timber would justify the cost. This would have to be determined on a case-by-case basis. Fertilization of forests is presently being practiced in Sweden and France. Finland plans to fertilize over 405,000 ha (one mil acres) to increase yields (29). A forest in France is used as the site for the land application of wastewater and sludge. The operation is quite successful in terms of wastewater renovation and tree growth.

Hardwoods--

Forest timber tracts--Table 16 lists the hardwoods grown in the U.S. The annual nutrient uptake of hardwood forests is very low when compared with agronomic crops. Table 17 gives the N, P, and K requirements for tree crops. It is interesting to note that most of the N taken up by the tree is returned to the soil during leaf fall. Hardwoods are not suitable for cultivation in management-intensive situations if the wood is to be used for sawtimber. Also, hardwood forests tend to be remote and accessibility to many of the sites is difficult.

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TABLE 16. TYPES AND DISTRIBUTION OF DECIDUOUS TREES (HARDWOODS) IN THE UNITED STATES

	Type of tree	Range	Major uses and growth factors
1.	Eastern Cottonwood (Populus deltoides)	New Hampshire to New York, central Michigan, Wisconsin, central Minnesota south and west to North Dakota, western Kansas, western Oklahoma and central and southeastern Texas and east to northwestern Florida and Georgia.	Pulp and Paper
2.	Plains Cottonwood (Populus sargentii)	Montana, Wyoming, eastern Colorado, northeastern New Mexico, and northwestern and northern Texas and north to western Oklahoma, Kansas, Nebraska and western South Dakota.	Pulp and Paper
3.	Tulip Poplar or Yellow Poplar (Liriodendron tulipifera)	Massachusetts and southern Vermont to New York and southern Illinois, southeastern Missouri, eastern Arkansas and Louisiana and east to central Florida.	Softwood, rapid growth. Reaches pulp size in 15 years, saw timber in 40-50 years. Lumber used in furniture and home construction.

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TABLE 16. (continued)

	Type of tree	Range	Major uses and growth factors
4.	Royal Paulownia or Princess Tree (Paulownia tomentosa)	Cultivated and naturalized in eastern U.S. from southern New York to West Virginia, southern Indiana, southern Illinois, and eastern Missouri and south to southern Texas and northern Florida.	Softwood, uses unknown, will reach 20 cm to 25 cm (8-10 in) in diameter in 10 years,seedingnaturally. Native to China.
5.	American Elm (Ulmus americana)	North Dakota, southeastern Montana, western Nebraska, western Oklahoma and central Texas, and east to Florida.	Will grow on many soils but requires additional water in dry regions. Desired soil pH 6.0-7.0. Susceptible to dutch elm disease. Source of lumber.
6.	Black Ash (Fraxinus nigra)	Maine to northeastern North Dakota, south to Iowa, Illinois, Indiana, West Virginia, Maryland and Delaware. Also, local in northern Virginia.	Grows best in a slightly acid, silt loam soil and should be grown only on moist sites. Desired soil pH 6.0-7.0. Source of lumber, pulp and paper.

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TABLE 16. (continued)

	Type of tree	Range	Major uses and growth factors
7.	Green Ash (Fraxinus pennsylvanica)	From Maine to Montana, northeastern Wyoming, northeastern Colorado and Kansas to central Texas, and east to northwestern Florida and Georgia.	Grows on relatively dry sites and is tolerant of alkaline soil. Desires soil pH 6.0-7.0. Wood for tools, pulp and paper.
8.	White Ash (Fraxinus americana)	Maine to northern Michigan and southeastern Minnesota, south to eastern Nebraska, eastern Texas and east to northern Florida.	It is moderate to fast growing and grows well on many soil types. Desired soil pH 6.0-7.0. Wood for tools, pulp and paper.
9.	Ailanthus, Tree-of-Heaven (Ailanthus altissima)	Cultivated and widely naturalized as a "weed" tree from Massachusetts to Iowa and Kansas, south to southern Texas and Florida and established to a lesser extent in western U.S. from southern Rocky Mountains to Pacific states.	A fast growing tree, most rapidly growing woody plant in U.S. Will thrive under extremely adverse conditions, growing as much as 2.44 M/yr (8 ft/yr). Annual sprouts 3.66 M (12 ft) long not uncommon where tree has been cut down. Immune to dust and smoke and may grow to a large size. Softwood has some lumber and fuel value.

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TABLE 16. (continued)

	Type of tree	Range	Major uses and growth factors
10.	White Oak (Quercus phellos)	Central Maine to Michigan and Minnesota, south to Iowa, eastern Kansas and eastern Texas, and east to northwestern Florida and Georgia.	A relatively fast growing hardwood which will grow on a variety of soils. Desired soil pH 5.0-6.0. Sources of lumber.
11.	Yellow Oak (Quercus muehlenbergii)	Vermont and New York, west to southern Michigan, southern Wisconsin and southeastern Nebraska, south to western Oklahoma, central and eastern Texas, east to northwestern Florida and Georgia, and north in mountains to Maryland and to western Connecticut.	Lumber.
12.	Black Oak (Quercus velutina)	Southwestern Maine to New York, Michigan, Wisconsin, southwestern Minnesota and southeastern Nebraska, south to eastern Texas, northwestern Florida and Georgia.	Grows at a moderate rate and will grow on a wide range of soils. Source of lumber.

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TABLE 16. (continued)

	Type of tree	Range	Major uses and growth factors
13.	Pin Oak (Quercus polustris)	Massachusetts and southern New York to Pennsylvania, southern Michigan, northern Illinois, southeastern Iowa, and eastern Kansas, south to northeastern Oklahoma, northern Arkansas, Tennessee and South Carolina.	Grows relatively rapidly for a hardwood on a wide range of soils, but becomes chlorotic on alkaline soil. Source of lumber.
14.	Post Oak (Quercus stellata)	Local in southern New England from southeastern Masschusetts to southeastern New York, southeastern Pennsylvania, West Virginia, Ohio, central Illinois, and southern Iowa, south to eastern Kansas, western Oklahoma and central Texas and east to northern Florida.	Grows at a moderate rate on many soil types. Source of lumber.
15.	Quaking Aspen (Populus tremuloides)	High mountains of western U.S. from Washington south to southern California, Arizona, New Mexico and sections of Texas, and north to Colorado, northwestern Nebraska, South Dakota and Montana, south in northeastern U.S. from northern and eastern North Dakota, extreme South Dakota, Iowa, Illinois, Ohio, West Virginia, Pennsylvania, New Jersey and Maine.	Wood for tools, pulp and paper.

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TABLE 16. (continued)

	Type of tree	Range	Major uses and growth factors
16.	Pignut Hickory (Carya glabra)	Southern New Hampshire and Massachusetts, west to New York, southern Michigan, Illinois and northeastern Kansas, south to southwestern Oklahoma and east to Arkansas, Mississippi, northwestern Florida and Georgia.	Grows at a slow to moderate rate and is adaptable to many soils, including dry sites. Sources of lumber.
17.	Bitternut Hickory (Carya cordiformis)	New Hampshire to New York, Michigan and Minnesota, south to southeastern Nebraska and eastern Texas and east to northwestern Florida and Georgia.	Lumber.
18.	White Birch (Betula alba, popyrifera)	North Dakota, Minnesota and northeastern Iowa, and east to northern Illinois, Michigan, Pennsylvania, New York and New England.	Lumber.
19.	Sugar Maple (Acer saccharum)	Northeastern U.S. to Minnesota, south to Iowa, eastern Kansas, Oklahoma and northeastern Texas, east to Louisiana and northern Georgia and north to Virginia and New Jersey.	Grows moderately fast. Grows best on fertile, well-drained soil. Desires soil pH 6.0-7.0.

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TABLE 16. (continued)

	Type of tree	Range	Major uses and growth factors
20.	Silver Maple (Acer saccharinum)	Maine to Michigan and Minnesota, south to southeastern South Dakota, eastern Nebraska and eastern Oklahoma, and east to Mississippi and Georgia.	Grows rapidly on a wide range of soils, tolerates mild soil alkalinity. Desired soil pH 6.0-7.0. Sources of lumber.
21.	American Beech (Fagus grandifolia)	Maine to northern Michigan and eastern Wisconsin, south to southern Illinois, southeastern Missouri, northwestern Arkansas, southeastern Oklahoma, and eastern Texas and east to northern Florida.	Grows at a moderate rate on many different soils including limestone soil. Desired pH 6.0-7.0. Sources of lumber.
22.	Sweetgum (liquidambar styraciflua)	Connecticut and southeastern New York, to Virginia, West Virginia, southern Ohio, southern Illinois, southeastern Missouri, Arkansas and southeastern Oklahoma, south to eastern Texas and central Florida.	Grows rapidly on moist, but well-drained soil. Desired soil pH 6.0-7.0. Lumber, pulp and paper.

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TABLE 16. (continued)

	Type of tree	Range	Major uses and growth factors
23.	Black Locust (Robinia pseudoacocia)	Native of Appalachian Mountains from Pennsylvania to northern Alabama and in Ozark Mountains of southern Missouri, Arkansas and eastern Oklahoma. Extensively naturalized in eastern half of United States.	Grows relatively rapidly on a variety of soils. Desired soil pH 6.0-7.0. Sources of lumber.
24.	Red Alder (Alnus rubra)	Pacific coast region from Washington and western Oregon to southern California.	Adds humus and nitrogen to the soil. Wood used for fuel, furniture, veneers and paper pulp.

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TABLE 17. NUTRIENT REQUIREMENTS FOR A CONVENTIONAL FOREST AND NUTRIENT APPLICATION RATES FOR FOREST CROPS

Type of crop	DMTE/hectare per year*	Rotation (yrs)	Fertilization (kg/hectare per year)			Reference
			N	P	K	
Conventional forest	3.14 - 6.05	30 - 80	66	9	80	Sopper and Kardos (30)
Pulp plantation	12.33	10	168	90	0	Salo, D.J., J.F. Henery R.E.,Inman (31)
Wastewater irrigated forest	-	-	233	98	212	Sopper and Kardos (30)
Biomass tree farm +	18	6	112	48	160	Inman, Salo, and McGurk,J. (32)
Biomass tree farm +	18	6	117	233	233	Inman, Salo, and McGurk,J. (32)
Biomass tree farm +	18	6	244	130	-	Inman, Salo, and McGurk,J. (32)

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TABLE 17. (continued)

Type of crop	DMTE/hectare per year*	Rotation (yrs)	Fertilization (kg/hectare per year)			Reference
			N	P	K	
Biomass farms (Hardwoods)						Inman, Salo, and McGurk, J. (32)
Wisconsin	11	6	64.5	12.3	69.3	
Missouri	16	6	90.3	17.0	97.60	
Georgia	18	6	103.2	19.6	111.1	
Illinois	18	6	103.2	19.6	111.1	
New England	11	6	64.5	12.3	69.3	
Washington	22	6	129	24.2	139.3	
Biomass farm	11	-	112	-	-	Zavitkovsky (33)
Wastewater application to a forest ‡	-	-	90-112	-	-	Environmental Protection Agency (34)

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TABLE 17. (continued)

Type of crop	DMTE/hectare per year*	Rotation (yrs)	Fertilization (kg/hectare			Reference
			N	P	K	
Experimental applications to a forest	-	-	112-224	67-112		Kitzmiller (35)
Cottonwood seedlings	-	-	224	168	224	Bonner & Broadfoot (36)

* Dry metric ton equivalent/hectare per year = metric ton/hectare per year.
+ Estimated application of NPK for given productivity by various methods.
‡ EPA design rate of wastewater application to forest land.

Research by Sopper (37) and Kenady (38) indicates that the introduction of sewage effluent and sewage sludge alters the forest environments drastically. Sopper reported that the understory vegetation that was present initially had all but disappeared after 10 years of land application of sewage effluent, and was replaced by more tolerant species. Kenady found that the response of vegetative growth to the added nutrients was significant. The increased vegetative growth served as shelter and food for herbivores and carnivores and thus their populations increased tremendously. It also appears that the vegetation that grew well in response to the added nutrients was not a preferred source of food for the increased herbivore population. As a consequence, the animals girdled the test tree seedlings being studied by Kenady and caused wholesale mortality to the seedlings. Studies by Sopper (37) and Urie (39) have demonstrated that some hardwood forest stands respond favorably to liquid and dewatered sewage sludge applications and to sewage irrigation with no signs of phytotoxicity.

The forest is a very delicate ecosystem, and environmental control is difficult. It is next to impossible to operate forest timber tracts as monocultures. Any introduction of nutrients will stimulate herbaceous growth which can serve as food for some of the animals that are a part of man's food chain. Thus, in terms of the definition of a non-food-chain crop, the usual forest crops that could be classified as non-food-chain crops should not be considered. Only those timber tracts that can be easily controlled should be considered for sludge applications.

The reforestation of clear-cut areas using sewage sludge could present a problem in that it is difficult to control competing vegetation and herbivores which could be detrimental to the desired tree crop (38). The external addition of nutrients will stimulate the growth of the understory as well as tree growth. Also, many clear-cut areas are remote, and the sites would have at best intermittent availability for sludge application. Forest fire devastated areas could also present similar problems.

Biomass production--Optimum biomass production for energy is dependent upon rapid establishment and early utilization of the growing capacity of the site. Optimized conditions for nutrients, water and tree growing space will be required for maximum yield. It has been estimated that 5.4 to 26.3 DMT of biomass/ha/yr (2.4 to 11.7 DT/acre/yr) can be obtained from a close-spaced (120 cm x 120 cm) plantation operating on a rotation period of six years (40).

Cottonwood, sweetgum, hybrid poplar, yellow poplar and sycamore have been studied for biomass production using municipal wastewater and waste heat (41). A close-spaced (0.9M^2 of growth space per tree) hybrid poplar plantation fertilized with sewage effluent yielded 75.9 DMT/ha (33.9 - DT/acre) of biomass after a 5-year growing period. The control plot (no sewage irrigation) yielded 25.8 DMT/ha (11.5 DT/acre) at the end of the 5-year growing period. Even though the survival rate (57%) for the wastewater irrigated plot was much lower than the control survival rate (87%), the wastewater irrigated plot resulted in increased viable biomass yields of 93% over the viable yields of the control plot.

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In another part of the study using both wastewater irrigation and waste heat, Sopper reported that after a year of growth, yellow poplar, cottonwood and hybrid poplar exhibited a greater mean height in plots receiving wastewater irrigation only. The sycamore and sweetgum had greater height growth in areas which were only irrigated or held as controls.

Another significant point established by this work is that the greater biomass yields were obtained on those plots that had the closest spacing. In fact it was shown that for each study, biomass production was inversely related to growing space, even though the greatest mortality occurred in the high density plots. A possible cause for the higher mortality in the wastewater irrigated plots was attributed to stimulated herbaceous vegetative growth, which provided a more favorable habitat for mice and rabbits. This was the same reason given by Kenady for the high seedling mortality rate experienced in his work (38). The very close tree spacing will prevent the passage of sunlight needed by the understory for photosynthesis; thus understory growth is inhibited. This further supports the idea of tree monocultures, rather than the use of the open forests.

Fiber production--A point often discussed among foresters is the change in the specific gravity of wood due to tree fertilization. Einsphar et al. (42) reported significantly lower specific gravities for aspens grown on irrigated and fertilized plots. Mitchell (43) concluded that the growth rate of hardwoods increased in the presence of N and that there was a positive trend toward increasing specific gravity with increasing growth rate. Saucier and Ike (44) found no change in tissue composition of sycamore due to fertilization. Murphy et al. (45) reported positive changes in red pine wood and red oak wood due to sewage effluent irrigation of these stands. The wood fibers were altered (specific gravity increased, percent latewood increased) and the utilization of these wood fibers as raw material for pulp and paper is enhanced.

It appears that the increased growth rate due to fertilization alters the properties of the wood in established stands. An increase in the specific gravity indicates an increase in the mass of fiber per unit volume. The increased fiber content of the wood makes it a more desirable pulpwood. Mitchell (43) found that red oaks responded favorably to irrigation using sewage effluent at a rate of 5 cm (2 in) per week. The specific gravity, percent latewood, and cell dimension changes in the trees were considered plus factors in the utility of the wood for pulp.

Softwoods--

Forest timber tracts--Table 18 lists the coniferous trees grown in the U.S. Softwoods constitute about 42% of the net sawtimber volume on commercial forestlands, with the Douglas fir, ponderosa pine, spruces, and eastern white and red pines being the most important softwoods. The Douglas fir constitutes by far the greatest timber reserve in the U.S. The Douglas fir becomes desirable for its lumber at heights of approximately 30.5 M (100 ft). This is achievable on good sites in fifty years, but this growth usually requires a period ranging from 60 to 100 years. Pulpwood can be obtained in about 20 years from softwoods in the southeast.

TABLE 18. TYPES AND DISTRIBUTION OF CONIFEROUS TREES (SOFTWOODS) IN THE UNITED STATES

Type of tree	Range	Major uses and growth factors
1. Longleaf Pine (Pinus palustris)	Coastal Plain from southeastern Virginia to central Florida and west to eastern Texas.	Lumber, pulp and paper. Needs adequate moisture, secondarily concerned with soil texture or chemical composition. Where soil moisture is limiting, its growth is inhibited. Requires good drainage for best growth and will grow on a wide range of soils. Desired soil pH 5.5-6.5.
2. Shortleaf Pine (Pinus echinata)	From northern Florida through the Gulf States to Texas and Arkansas and north on the piedmont and coastal plain from Georgia to Virginia and on the Delaware peninsula.	Lumber, pulp and paper. Closely associated with loblolly pine throughout most of the inland or upper portions of the Gulf Coastal Plain. Requires well-drained soils with a desired pH 5.5-6.5.
3. Loblolly Pine (Pinus taeda)	Eastern Texas and southern Arkansas to central Florida and north on the piedmont and coastal plain through the Carolina's to tidewater Virginia, the Delaware peninsula and Cape May, New Jersey.	Lumber, pulp and paper. Prefers wet sites, attaining maximum growth on poorly drained, moisture-holding clays and clay loams, and often displays its best development on the edges of swampy areas. Will grow on a wide range of soils. Desired pH 5.5-6.5.

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TABLE 18. (continued)

Type of tree	Range	Major uses and growth factors
4. Slash Pine (Pinus caribaea) (elliotti)	Coastal Plain from southeastern Carolina to central Florida and southeastern Louisiana.	Lumber, pulp and paper. Found naturally in the drainage of Coastal Plain longleaf forests east of the Mississippi River, in the moderately-drained flatwoods of the southeast. Will grow on a wide range of soils. Desired soil pH 5.5-6.5.
5. Pond Pine (Pinus serotina)	Coastal Plain from southern New Jersey and southeastern Virginia, south to central and northwestern Florida and Alabama.	Pulp and paper.
6. Ponderosa Pine (Pinus ponderosa)	Widely distributed, chiefly in the Rocky Mountains and mountains of Pacific Coast region from southwestern North Dakota and Montana, Washington and Oregon to southern California, east to Arizona and Texas, north to New Mexico, Colorado, western Nebraska and Black Hills of South Dakota.	Lumber.

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TABLE 18. (continued)

Type of tree	Range	Major uses and growth factors
7. Lodgepole Pine (Pinus contorta)	Western United States from Washington to southern California and western Nevada and from Idaho and central Montana south to Wyoming, northern Utah and Colorado.	Lumber.
8. Jack Pine (Pinus banksiana)	Great Lakes states of Minnesota, Wisconsin, Michigan, and locally plentiful in Maine, northern Illinois, northwestern Indiana, northern New York, Vermont and New Hampshire.	Pulp and paper. Normally occurs in drier sandy soils. Over half the volume of growing stock is found in Maine where it develops best. Higher soil nutrient levels in that state are responsible.
9. White Pine (Pinus strobus)	Minnesota, northeastern Iowa, northern Illinois, northwestern Indiana, Ohio, Pennsylvania and New Jersey, and south in the mountains to western North Carolina, northern Georgia and Tennessee.	Lumber, pulp and paper. Occupies sites having a wide range of moisture and nutrients. It requires better site quality for optimum development than other native pines.
10. Douglas Fir (Pseudotsuga menziesii)	Pacific coast region from western Washington and Oregon to central coastal California and central Nevada.	Timber, reforestation and ornamental Christmas trees and lumber. Grows rapidly. Does best on sandy to silt loam and tolerates alkaline soil. Desired soil pH 5.0-6.0.

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TABLE 18. (continued)

Type of tree	Range	Major uses and growth factors
11. Balsam Fir (Abies balsamia)	Minnesota, Wisconsin, Michigan, northern Pennsylvania, New York and New England.	Lumber and popular Christmas trees. Grows best in moist soils.
12. Englemann Spruce (Picea engelmannii)	Mountains of western United States from Washington to northern California, eastern and southeastern Nevada, southeastern Arizona and southern New Mexico and north to central Colorado and central Montana.	Lumber.
13. Blue Spruce (Picea pungens)	Rocky Mountains region in high mountains from western Wyoming and southeastern Idaho south to Utah, northern and eastern Arizona, New Mexico and central Colorado.	Lumber. Grows best on well-drained soils with pH 5.0-6.0.
14. Red Spruce (Picea rubens)	Maine south to eastern New York, northeastern Pennsylvania and northern New Jersey. Also, south in Appalachian Mountains of western Virginia, western Maryland, West Virginia, western North Carolina and eastern Tennessee.	Lumber. Grows best on well-drained soils in the highlands with pH 5.0-6.0.

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TABLE 18. (continued)

Type of tree	Range	Major uses and growth factors
15. Western Red Cedar (Thuja plicata)	Pacific Coast region from western Washington and Oregon to northwestern California. Also, eastward in Rocky Mountains from eastern Washington, northern Idaho and western Montana.	Lumber.

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Trees for pulp are quite frequently produced in plantations or monocultures. Monoculture operations appear to be suitable for sewage sludge applications. Data in the literature indicate that the softwoods do respond favorably to fertilization using sewage effluents and sludge (45, 46). Zasoski et al. (46) found that sludge applications of 112 and 224 DMT/ha (50 and 100 DT/acre) to a Douglas fir forest caused an unidentified toxicity. At sludge concentrations of 22.4 and 45 DMT/ha (10 and 20 DT/acre), the 10 and 20 year old plots of Douglas fir showed a growth increase.

The presence of the nutrients added to the soil by the sewage will stimulate herbaceous growth. Because this growth may adversely affect tree growth, cultural treatments may be required if the tree spacing is too wide. Close tree spacing may reduce the number of cultural treatments, but the close spacing on the other hand might restrict the use of sewage sludge applications. Thus, these close spacing operations maybe more amenable to sewage irrigation rather than sewage sludge application.

Biomass production--Energy farms, as presently being studied, consist of rapidly growing tree species that are capable of growing by coppicing (sprouting from stumps). Conifers, with the exception of the redwoods, do not coppice, and are somewhat slow in establishing growth; thus tree biomass production has been centered primarily around the hardwood species. However, the loblolly pine does meet most of the criteria for candidate biomass species.

Fiber production--Trees grown for fiber only do not have to meet the same requirements as trees grown for sawtimber. In fact, when fertilized, these trees may produce more fiber per unit volume, and research has shown that fertilization of forest trees tends to produce a tree with more desirable pulpwood properties (43).

The more conventional tree plantations operate on a 30 to 80 year rotation period, but several of the commercial paper industries are experimenting with trees that have a rotation period of 8 to 15 years. Plantations that are operated using these fast rotation periods are management-intensive and costly. However, it appears that these plantations could benefit from the addition of sewage sludge for the restoration of nutrients. If close-space planting is practiced, weeds and other herbaceous growths could be reduced considerably. Tree growth rate increases of up to 100% using sewage irrigation have been reported (45). However, whether the increase in fiber volume would be significant enough to offset the cost of the operation is not known.

Summary--

A list of some of the fast growing tree species and their market uses are given below.

1. Pines (Pinus sp) - native species, pulp size in 15 years, timber in 20-30 years. Procedures for cultivation presently developed.

2. Tulip Poplar (Liriodendron sp) - native species. Reaches pulp size in 15 years, sawtimber in 40-50 years.

3. Black Locust (Robinia sp) - native. Pulp and fence-post size in 15-20 years; resprouts after cutting.

4. Ashes (Fraxinus spp) - native species. Pulp size in 20 years; sawtimber in 50 years.

5. Poplar Hybrids (Populus spp) - softwood, rapid growth.

6. Empress Tree (Paulawnia tomentosa) - from China. Wood soft; uses unknown; will reach 8-10 inches in diameter in 10 years; seeding naturally.

7. Tree-of-Heaven (Ailanthus) - from Asia. Widely established along roadsides and forest edges. Rapid growth; root sprouts. Should give a crop of pulpwood every 15 or 20 years.

Any of the hardwoods and softwoods amenable to plantation growth or to growth under intensive management practices could be cultivated using sewage sludge as a fertilizer. However, the application of sewage sludge is more easily achieved on normally-spaced plantations. This spacing practice would allow a greater proliferation of herbaceous growth, and thus cultural treatments for the control of weed growth would be required. On the other hand, closer spacing would tend to inhibit understory growth, but this would also decrease the ease with which sewage sludge could be applied.

The above information does show that sewage sludge could be used as a source of nutrients for the cultivation of the following timber tracts:

1. Softwoods grown in monoculture operations for the production of pulpwood and other wood byproducts.

2. Softwoods that reach maturity in 10-20 years.

Forest Nurseries

The production of tree seedlings using sewage sludge is very promising. Forest seedlings are fertilized and have a rotation period of 6 months to 2 years. The seedlings are usually produced under controlled conditions and, thus, would have minimal impacts on the forest ecosystem or food web.

Gouin et al. (47) reported that the Norway spruce and white pine seedlings grew well on composted sewage sludge. He also found that an application rate of 224 MT/ha (100 tons/acre) was sufficient to yield two crops of deciduous seedlings over a four and one half year period. Kenady (38), working in the open forest environment, found variable response to dewatered sludge by softwood seedlings. He accounted for the variation in response based on seedling acceptability of, or tolerance to, the sludge and to competing vegetation that developed on the growing sites.

In terms of seedling response to dewatered sludge, Kenady ranked the Douglas fir as the best, and the Sitka spruce, ponderosa pine and western hemlock as two, three and four, respectively.

The Forest Service reports that there are approximately 170 forest tree nurseries in the U.S. (48). These nurseries are both bareroot and container operations. The bareroot operations have approximately 4,050 ha (10,007 acres) available for production and the container operations add another 16.2 ha (40 acres) to this production capacity. In 1976 over one billion seedlings were grown for forest and windbarrier plantings. This industry is in a prime position to utilize sewage sludge as a source of fertilizer and as a soil conditioner for the production of crops.

Most of the seedlings produced in Federal nurseries (1.1 x 10^8 in 1976) are planted on National Forest lands. The seedlings produced in forest industry nurseries are generally planted on company lands (396 x 10^6 seedlings in 1976), but some of these seedlings are distributed to other private landowners (49). Reforestation projects annually involve over 700,000 ha (1.73 mil/acres). Special purpose plantings, which include a) recently cutover land, b) plantings exclusively for Christmas trees, c) plantings for surface mine reclamation, and d) plantings for wildlife purposes, are included in the reforestation projects. Forest industries (pulp, timber, etc.) alone planted 421,000 ha (1.04 mil acres)in 1976.

Gouin _et al_. (47) has shown that deciduous and coniferous seedlings grow very well in composted sludge amended plots. Their work supports that of Berry and Marx (50) and it thus appears that the optimum soil application levels of the composted sludge for the production of seedlings are in the range of 112 to 224 MT/ha (50 to 100 tons/acre).

Kenady (31) studied the response of coniferous seedlings to sewage sludge. He reported a variable response among the seedlings, and attributed the variation to seedling species, the tolerance of the seedlings to the sludge characteristics, and to the competing vegetation that developed on the planting sites. Kenady used dewatered sludge application rates ranging from 10 cm to 15 cm per year. The species recommended for planting in sludge, based on his data, are the Douglas fir, Sitka spruce, ponderosa pine and western hemlock, in that order.

Summary--

Forest seedlings established in container operations or in plantation style bareroot operations using sewage sludge have been shown to be equal to and even superior in quality and quantity to seedlings established using standard fertilizers. Sewage sludge can replace the nutrients removed from the soil when the seedlings are extracted, and the sludge can be used to keep the soils productive and thus can be substituted for green manure or peatmoss.

The use of sewage sludge for these crops would reduce the possibility of food chain health risks considerably - the crops produced are inedible and the

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soil containing many of the residues of concern is removed with the plant. Thus, the risks associated with using the land for other purposes at some future time are also minimized.

Flax and Flaxseed

Flax is one of the twenty principal crops planted in the U.S. (51). As of 1974, 809,400 ha (2 mil acres) were under cultivation for the production of this crop. It is best adapted to medium loam or clay soils, but grows best in well-drained sandy loam soils in temperate climates. In most areas, planting of the same land with flax is limited to once every six years to avoid soil exhaustion. If planted with greater frequency, heavy applications of fertilizer are required. The usual practice is not to fertilize a flax crop, but when it is necessary, N and P are the nutrients required. Crop yields of approximately 1.4 M^3 (40 bushels) are obtained on 0.405 ha (1 acre). Nutrient requirements per ha are approximately 23 Kg (50 lbs) of N, 11 Kg (25 lbs) of P as P_2O_5 and 7 Kg (15 lbs) of K as K_2O (51).

There are no reported studies on the response of flax to cultivation using sewage sludge. However, soil that supports wheat, rye and soybeans will also support flax. There are documented studies by Sopper and Kardos (32) on wheat and by Hinesly (52) on soybeans that show that these crops respond favorably to sewage sludge. Increased yields were obtained in each case and these crops were quite efficient in removing the nutrients applied to the sites in the sludge. Thus it can be assumed that flax grown under the same conditions would show similar responses.

Sludge application for flax seed production may be beneficial in supplying this crop with the relatively high nitrogen requirements. Studies on the growth of flax have shown that flax grown on soils with a high N content have a low fiber content. However, the market for linen has declined due to an increase in the use of polyesters, and because the linen industry is very labor intensive. Therefore flax is not usually grown for fiber production in the United States. Flax seed is grown in the U.S. A market does exist for linseed oil which is used for the production of paints, varnishes, linoleum and oil-cloth.

Horticulture (Environmental) Specialties

The horticulture specialties show great potential for cultivation using sewage sludge. In fact, the industry could profit from the use of sewage sludge in light of the increasing costs of commercial fertilizers.

Nutrient requirements for the horticulture specialties, which include both NFCC varieties as well as food-chain varieties, do not vary for each kind of plant or species, rather only for the three major classes of plants. Although vegetables are one of the three major plant species, they are not being considered in this study. The remaining two major plant species are:

1. Small Decorative Flowering Plants
    a. perennials

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b. bulbs
c. annuals

These plants require twice as much P and K than N. Too much N stimulates leaf, and hence top growth at the expense of the flowers wanted. Phosphorus produces flowers and strong roots, and K produces strong stems and vigor in roots. The recommended commercial fertilizers have NPK ratios of 5-10-10 or 5-9-7. Liquid sewage sludge has an approximate NPK ratio of 1-1-0, and composted sewage sludge has approximately the same NPK ratio as liquid sewage sludge, with nitrogen being reduced by about two-thirds.

2. Wood plants

a. trees
b. shrubs
c. climbers
d. hedges

These plants need more N than P or K due to more leaves and hence the need for more chlorophyll.

Studies by Kirkham (53, 54) under greenhouse conditions on tulips and chrysanthemums showed that these flowers grew well when fertilized with liquid sludge as the only nutrient source. There were no significant differences in the growth and health of tulips grown with tap water, primary effluent or organic liquid sludge. The tulips grown with dried organic sludge produced buds, but did not open by the end of the experiment (20 days). She concluded that the tulips grew better with liquid sludge than dried sludge, and that this could indicate that more sludge could be applied on the surface of the soil than could be mixed or injected into the soil. The data also indicated that the high soluble salt levels in soils treated with organic sludges could be harmful to some salt sensitive plants such as the tulip. Epstein and Parr (55) also reported that the excess soluble salts in potting mixtures using sewage sludge compost may be a problem. However, they suggested that leaching the mixture with water could alleviate that problem. This was also reported by Hinesly (52).

The chrysanthemums studied by Kirkham (54) responded most favorably to a sludge irrigation rate of 50 ml per pot per week. An irrigation rate of 100 ml/pot/ week produced plant leaves that had necrotic margins. The necrosis was attributed to sludge ponding and poor aeration in the media, rather than to any nutrient deficiency. The chrysanthemum plants irrigated weekly with 50 ml of liquid sewage sludge had similar nutrient compositions except for N and K when compared with those plants that were treated with standard amounts of liquid or pelletized inorganic fertilizers. Nitrogen was higher and K lower in the sludge treated plants. However, the lower K concentration did not reduce yields or cause any deficiency symptoms.

The turf grass industry has the greatest potential for the utilization of sewage sludge. In the State of Maryland, this industry is a rapidly expanding segment of Maryland's agricultural economy (56). In recent years, growth in the turf grass industry has exceeded overall agricultural expansion. As of 1974, 34,000 ha (85,000 acres) were under cultivation for the production of sod. The sod industry is estimated today to be a $2 million industry. The cultivation of this crop using sewage sludge is ideal since the crop is removed and transported to another area which reduces the accumulation of residues at the growing site.

Sod needs a deep sandy loam soil with some clay and silt to hold nutrients. Sod is sometimes grown on organic soils (mulches and peats) which are excellent from the standpoint of growth and ease of cutting operations. However, it has been reported that sod grown on organic soils has a tendency to be coarser and more open, and does not hang together as well as sod produced on sandy loam soils (57). But research conducted by Darrah *et al.* (58) indicated that the best turf growth resulted from seed bed preparation with composted sewage sludge and maintenance fertilization with liquid digested sludge. They found that the sod with the highest shear strength resulted from the high sludge treatment after seeding. Based on interviews with sod farmers, it appears that not enough sewage sludge is available. It is their opinion that the crops respond favorably to fertilization using the sludge, and that they will use it as long as they can obtain it. Grasses in general require large amounts of N (59) for cultivation, and, thus, would be an ideal non-food crop for sewage sludge applications. The grasses can be grown for sod, for seed or for energy (for the production of alcohol). In terms of quantities of sewage sludge, most lawns will require about 8 Kg (17 lbs) of processed sewage sludge, or 23 Kg (50 lbs) of liquid sewage sludge per 93 M^2 (1,000 ft^2) once or twice a year.

Generally shrubs and trees are fertilized between December and April. Fertilizer is only applied once per year. Flowering shrubs and ornamental trees greater than 7.62 cm (3 in) in diameter require 45 Kg of N/ha (40 lbs of N/acre), 90 Kg of P/ha (80 lbs of P/acre), and 45 Kg of K/ha (40 lbs of K/acre); foliage shrubs require 90 Kg of N/ha (80 lbs of N/acre), 56 Kg of P/ha (50 lbs of P/acre), and 34 Kg of K/ha (30 lbs of K/acre); and ornamental trees with a diameter less than 7.62 cm (3in) require only 1/4 the NPK requirements as trees with diameters greater than 7.62 cm (3 in) (59).

Interviews with large nursery owners in the D.C. area revealed some interesting points. For the most part, the usual practice is to fertilize once at the time of planting and no more. Any increase in the rate of fertilization would stimulate new, uneven growth of the trees and shrubs. This growth must be cut back to shape the trees and shrubs; otherwise they would become spindly or the shape distorted and thus the tree or shrub would be undesirable. Between crops, a cover of rye seed is planted, allowed to grow to one inch and then plowed under to incorporate organic matter back into the soil. Therefore, it appears that composted sludge would be beneficial to this industry and Gouin has shown that composted sludge makes a good potting mix (47). The compost could also be used as a mulch to provide the organic matter and to hold water.

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Thus, the horticultural industry could benefit by using sewage sludge, but rates of application and the form in which the sludge would be most suitable would have to be determined on a case-by-case basis.

Cotton and Soybeans

Cotton and soybeans were included in this study because these crops have many potential inedible uses as listed in Table 19. The oil extraction process used for purifying the oils rejects all the impurities, and the meals can be used for the production of inedible products.

It has been reported that cotton will not grow well when irrigated with sewage effluents that have high boron concentrations (60). Boron is phytotoxic to cotton. This element has the tendency to remain in the wastewater and to move with the soil-water system (61). It is doubtful that sewage sludges would be toxic to cotton since boron is not concentrated in the sludges.

Because of the high N demand, the best crop yields are obtained when cotton is fertilized. In those areas where the crop is not fertilized, crop rotation is practiced to prevent soil nutrient exhaustion. The average annual fertilizer requirements of cotton are 82 Kg/ha (73 lbs/acre) of N, 60 Kg/ha (53 lbs/acre) of P as P_2O_5 and 70 Kg/ha (62 lbs/acre) of K as K_2O (51).

Soybeans are not normally fertilized since the plant has the ability to fix N. However, studies by Hinesly (52) show that soybean crop yields can be increased by fertilization with sewage sludge. In that study, the soybeans grown on plots with 25.0 mm of sludge had elevated metal concentrations in the tissues, and did succumb to phosphorus toxicity. However plants grown on the plots with sludge applications of 6.4 mm and 12.7 mm showed elevated metal concentrations, but no phytotoxicity was observed.

Over 28 x 10^6 ha are devoted to raising cotton and soybeans in the U.S. (51). The leading states in cotton and soybean production, as shown in Figures 1 and 2, contribute more than 80% of the sludge generated in the U.S. annually. Based on the pounds of N, P, and K applied to cotton and soybeans in 1973 as shown in Table 20, the substitution of sewage sludge (based on N) for commercial fertilizers would require an annual utilization of more than 40% of the sludge generated. The actual percentage of sewage sludge that could be used would of course be considerably lower, but the potential is there.

Presently, the edible usages for cotton and soybeans far outweigh the inedible usages. However, one scenario for these crops could be the selection of one or two states in which these crops would be grown strictly for their inedible usages. The residues remaining after harvesting and processing would be used for energy biomass. This scenario if implemented could involve the utilization of about 15% to 20% of the sludge generated annually in the U.S.

TABLE 19. NON-FOOD-CHAIN-CROP USES FOR COTTON AND SOYBEANS

COTTON

A. Fiber

Textiles

B. Linters

1. mattresses
2. coarse yarns
3. paper
4. packing material

SOYBEANS

A. Oil

1. High grade industrial enamels
2. Varnish
3. Alkyd resin paints
4. Inks and stains
5. Sealing and caulking compounds
6. Synthetic rubber
7. Drying oils
8. Polishes and waxes
9. Synthetic organic detergents
10. Toilet preparation including shampoos
11. Cosmetics
12. Soap

continued

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TABLE 19. (continued)

  13. Lubricants
  14. Resins and plastics
  15. Fatty acids (surfactants, esters and scents)

B. Meal (Protein)

  1. Adhesives
  2. Paper coatings
  3. Water-thinned paints
  4. Plastics
  5. Textile fibers
  6. Fire foam stabilizers
  7. Printing inks
  8. Fillers
  9. Core binders
  10. Linoleum
  11. Emulsifying agents
  12. Paper and textile sizing
  13. Leather finishes
  14. Fertilizer
  15. (Active industrial research for new uses)

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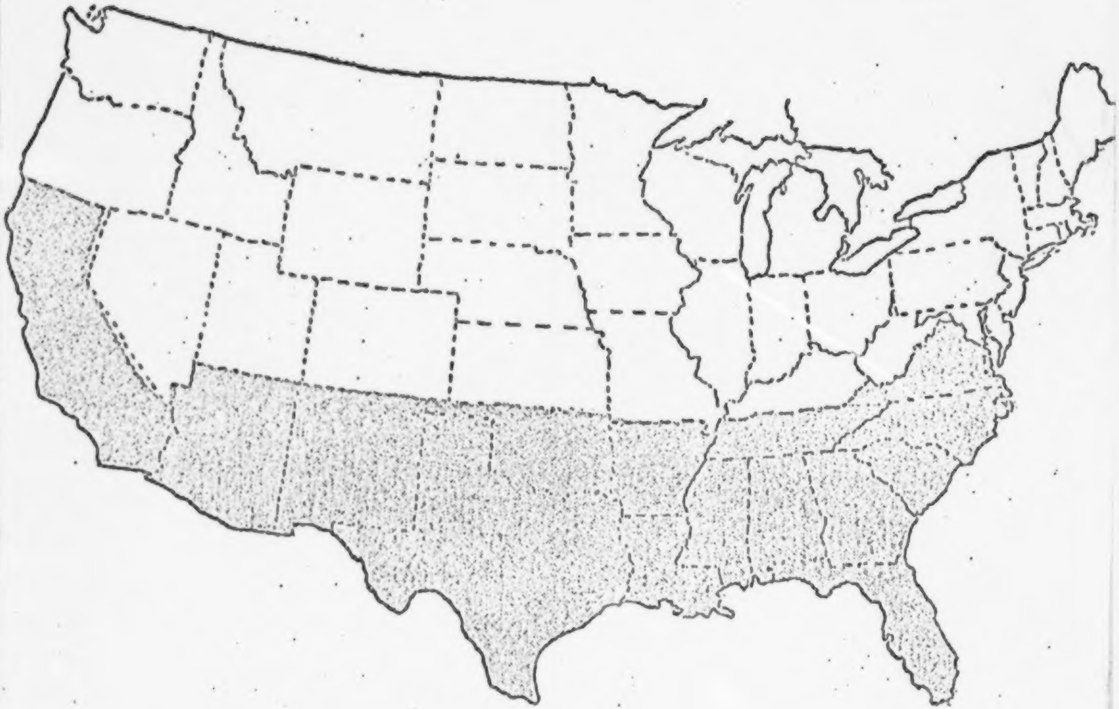

FIGURE 1. States with significant cotton production (shaded area)

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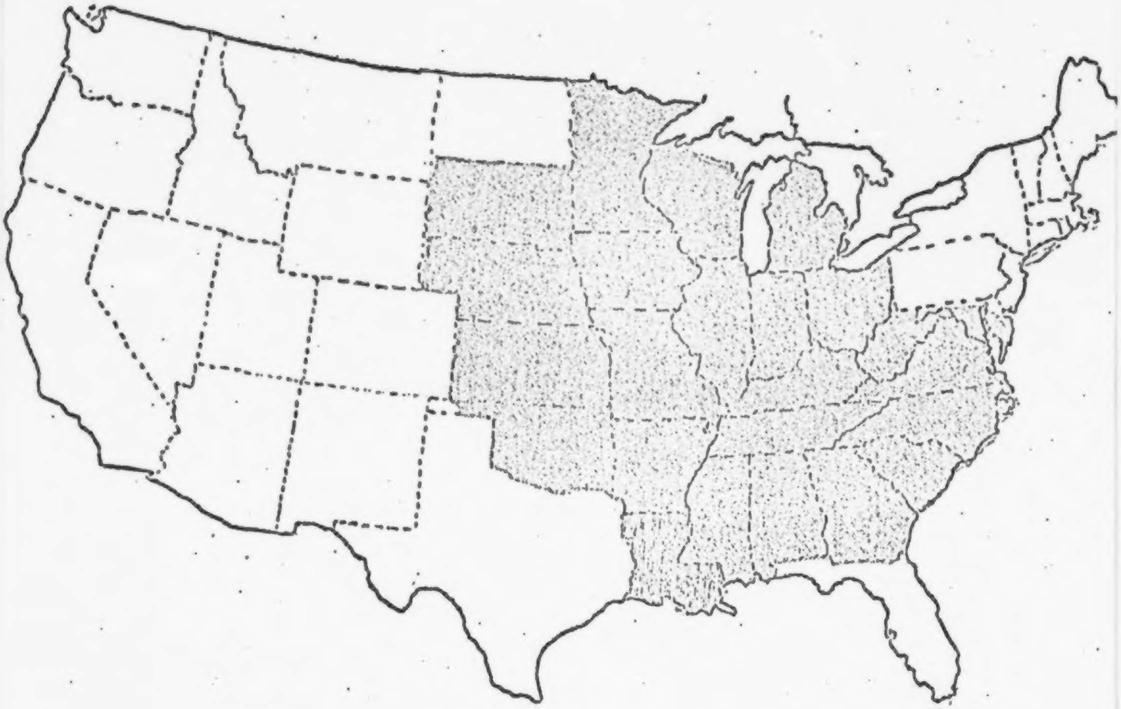

FIGURE 2. States with significant soybean production (shaded area)

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TABLE 20. KILOGRAMS OF N, P, AND K APPLIED TO COTTON AND SOYBEANS (51)

Item	N (Kg/ha/yr)	(P_2O_5) (Kg/ha/yr)	K_2O (Kg/ha/yr)
Soybeans	16	47	62
Cotton	82	60	70

Hemp, Jute and Sisal

Hemp, jute and sisal are not major U.S. crops. The products from these crops are presently being imported. They are amenable to cultivation using sewage sludge. The U.S. grew hemp during World War II when its supplies from Japan were cut off, but presently it does not appear that there are any economic advantages for the U.S. production of these crops.

The jojoba, guayule and euphorbia are plants that have potential economic value. Suitable strains of these crops could possibly be cultivated using sewage sludge as the source of nutrients. However, much research is needed on the growth requirements of these crops. It is recommended that fertilization of these crops using sewage sludge be investigated. This would be an excellent use for the sludge since a valuable resource would be used to produce valuable products that could reduce the nation's dependancy on imported products. The jojoba is presently being studied extensively at the University of California, Riverside Campus.

The jojoba is a hardy scrub bush which produces a seed from which oil can be extracted. The plant grows best in arid climates. The oil is very similar to whale oil, and could be used as a substitute. The guayule bush grows in the deserts of the United States. The bush produces a latex which has the potential of being as versatile as the latex produced by the rubber tree. The euphorbia plant grows naturally in the semi-arid areas of California. The leaves produce a latex which, when mixed with acetone, yields an oil that behaves as crude petroleum.

MOST PROMISING NON-FOOD-CHAIN CROPS

For this study the most promising NFCC were selected from the initial list of 20 crops using the stated criteria. Based on the above discussion of each crop category and by application of the criteria, six crops (or crop categories) emerged as best meeting the goals of this study. These crops and categories are given in Table 21.

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TABLE 21. MOST PROMISING NON-FOOD-CHAIN CROPS SUITABLE FOR CULTIVATION USING SEWAGE SLUDGE

Category	Crop
Timber Tracts	Monoculture timber tracts operations using softwoods
Forest Nurseries	Hardwood and softwood seedlings
Horticulture Specialties	Sod
Research Crops	Energy biomass trees
Oil Crops	Cotton Soybeans

Discussion of Selection Process

6-1/2"

Timber Tracts--

The feasibility of using sewage sludge as a source of nutrients for the cultivation of hardwood forests, while possible and currently being studied by other researchers, was not judged to be acceptable by this study because:

1. The optimum growth for hardwoods is best achieved in the open forest environment and the impacts of sewage sludge on the forest ecosystem have not been fully determined.
2. The N and P requirements for hardwoods are low when compared with other crops and thus this use of sewage sludge would constitute a disposal technique rather than a nutrient recovery technique.
3. Hardwoods have a very slow rotation period and the sites tend to be remote and intermittently accessible.
4. Hardwood forests in general are not in close proximity to sludge generation centers.

On the other hand, softwoods are amenable to cultivation in monocultures and the impacts of sewage sludge on those environments would be negligible. Monoculture operations are accessible and the sites are not that far from sludge generation centers. While the nutrient requirements for softwoods are low when compared with other crops, the faster rotation periods for some species could justify the consideration of sewage sludge as a source of nutrients. However, the period of application would at best be once every ten years.

Some of the softwoods do appear to be amenable to cultivation using sewage sludge and thus this crop was retained as a crop meriting further study.

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Forest Nurseries--

The operation of forest nurseries for the production of forest tree seedlings met all of the criteria considered in this feasibility study. Thus, this crop category was retained for further study.

Flax and Flaxseed Farms--

Even though this crop category scored favorably during the analysis phase of this study, it was decided to delete it from further consideration because the market for this crop is declining and the possibility does exist that some of the land used to raise this crop would be used to grow a food crop.

Horticulture Specialties--

This crop category met essentially all of the criteria considered, and many nurseries and gardeners cultivating crops that are in this category are currently using sewage sludge as a soil conditioner and as a source of nutrients. Thus, this category was retained for further study.

Research Crops--

A lot of interest was generated in trying to determine if any of the research crops selected were suitable for cultivation using sewage sludge. The jojoba, guayule, and euphorbia grow in arid climates presently. While it was felt that suitable strains could be developed, there was just not enough available data to determine feasibility. Thus, it is recommended that those researchers working with these crops investigate the potential of using sewage sludge as a source of nutrients for the cultivation of the crops.

The feasibility analysis did show that energy biomass crops could benefit from the use of sewage sludge as a source of nutrients and thus they were retained for further study.

Oil Crops--

Cotton and soybeans are food-chain crops and thus clearly do not fit objectives of this study. However, they were included under the category of oil crops because the oil purification process could be adjusted to exclude any metals that might be present. This is true for any crop that is purified such as sugar cane and sugar beets. However, it was felt that these crops should be studied because they met every criterion, except the definition. While there are many oil crops that could utilize the N and P in sewage sludge, it was felt that the inedible uses of cotton and soybeans were just too great to be overlooked. These crops are cultivated in areas very close to major sludge generation centers and the rotation periods are fast enough to allow major quantities of sludge to be used. Thus, these crops were retained for further study.

SECTION 7

CASE STUDIES

METHODOLOGY

Three NFCC crops were selected for in-depth case studies. The crops were selected based on discussions with EPA and the project data collected. Each case study examines the feasibility (in terms of land requirements and costs) of supplying the necessary N and P to the crop through the application of sewage sludge in lieu of commercial fertilizers. The sludge would serve to replace or reduce the application of fertilizer and soil nutrients. Data on increased crop yields are not definitive and are therefore not included in the study.

The feasibility analysis has shown that there are many NFCC that could be produced using sludge as a source of N, P, and organic matter. Basically, any crop requiring N and P could be cultivated using sewage sludge provided that there are no materials in the sludge that would be phytotoxic to the crop. In addition, the sludge can also serve as a soil conditioner. For certain crops, K and other minerals might have to be added as supplements if they are absent in the soil. Also, depending on the soil conditions and the crop, lime might be needed to maintain proper soil pH levels and to insure immobilization of some of the metals that might tend to become bioavailable to the plant.

Sewage sludge does not contain materials that could be potentially toxic to any of the crops reviewed here based on documented data. Phosphorus phytotoxicity to some of the crops has been documented, but this situation was easily corrected by leaching the soil with water.

Because it appears that sewage sludge could provide the necessary N and P for many NFCC, it is necessary that other factors be taken into consideration before crops are selected for cultivation. The intent is to derive beneficial uses of the sludge and to produce crops that are of benefit and use in the market place. Much of the research and many of the pilot studies on beneficial uses of sewage sludge have produced products that have little or no market potential. Consequently, the sludge product has been given away and/or stockpiled and the crop produced has been given away or plowed under. Unless markets are available or have been identified, all efforts in this area become exercises in futility.

The crops selected for the case studies are currently being sold on the open market, with the exception of the research crops. Because these crops are being actively marketed and in the case of biomass crops, actively researched, the following information is available:

1. the preferential climatic condition for the crop;

2. the nutrient requirements of the crop (this information is necessary, since beneficial sludge uses are being analyzed and not sludge disposal alternatives). This information is used for the determination of the potential amount of sewage sludge that should be used to supply necessary N and/or P requirements;

3. the economic crop size (i.e., the amount of land presently under cultivation), the land area required, and the minimum size of a city that could generate enough sludge to support crop production.

If the cost of supplying nutrients to a crop can be reduced by using sewage sludge rather than commercial products, then this beneficial use of the sludge should gain in popularity. Thus, a simple cost/benefit analysis was performed to determine the costs involved for using sewage sludge in this manner. Those costs were then compared to the costs involved for the use of commercial products to supply the crop nutrients. Benefit, as used in the cost/benefit analysis, is the difference between the wholesale purchase price of the commercial source of nutrients and the wholesale purchase price of the alternative source of nutrients, in this case, sewage sludge (the purchase price is assumed as no cost to the farmer in this study, unless otherwise noted). Cost, as used in the cost/benefit analysis, is defined as the aforementioned wholesale prices and does include labor and equipment required for land application, but it does not include the costs for environmental monitoring and the cost of land.

Crops Selected for The Case Studies

The following crops were selected for case studies:

1. Cotton
2. Sod
3. Energy Biomass Trees

These crops were selected because sufficient documented information was available for those crops to quantify the sludge requirements and to estimate the costs incurred for supplying nutrients. Other factors such as: (1) uses for the crops; (2) markets available for utilization of the crops; and (3) crop growth habits and constraints have been discussed in other sections of this report. Figures 1, 3 and 4 show the geographical locations of growth for each of the crops selected for the case studies.

Acceptability

There appear to be no significant barriers to sludge utilization for the production of the selected crops in the context presented. These crops would be excluded from man's food chain and thus, it is likely that there would be no adverse reaction from the general public.

The full scale use of sludge for the production of these crops would involve considerable changes to current fertilizer application practice.

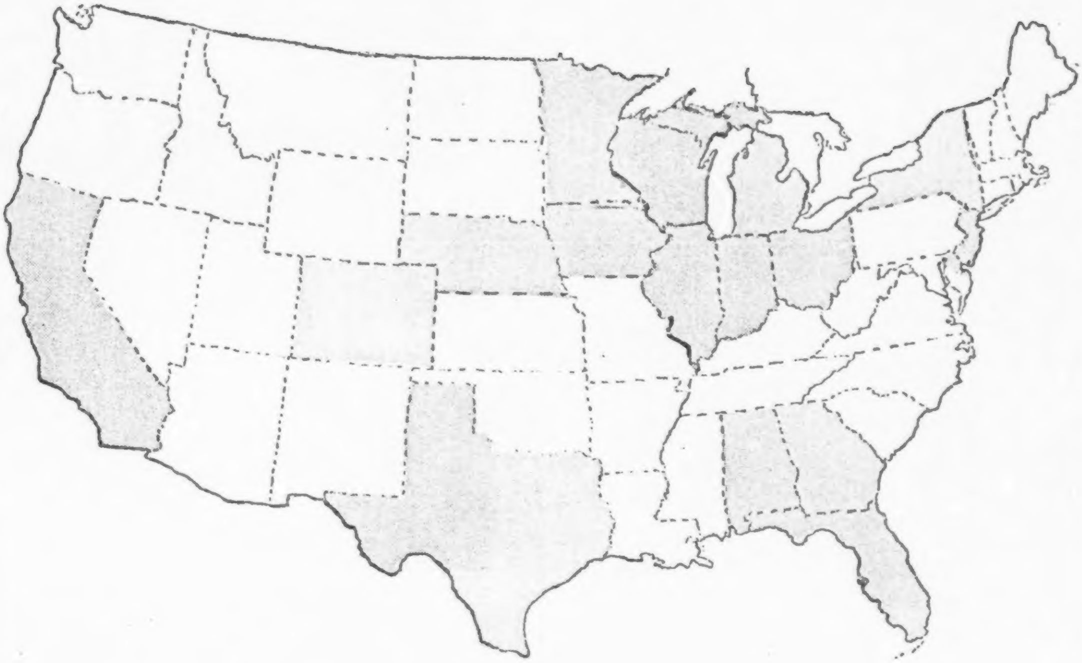

FIGURE 3. States with significant sod production (shaded area)

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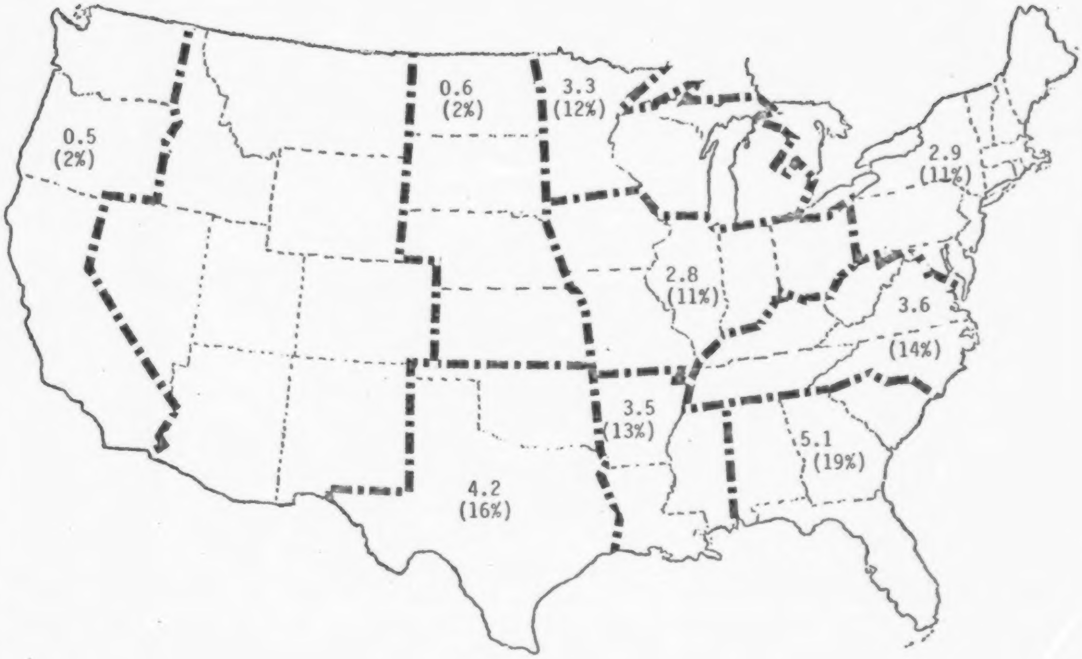
0.5
(2%)
0.6
(2%)
3.3
(12%)
2.9
(11%)
2.8
(11%)
3.6
(14%)
3.5
(13%)
5.1
(19%)
4.2
(16%)

FIGURE 4. Millions of acres and percentage of land potentially available for energy biomass tree production by region (assuming the utilization of 10% of the non-agricultural land in each region)

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Sludge application equipment tends to differ from that used for chemical fertilizers; odors may develop or be present whenever sludge applications occur and for a time thereafter; and on-site storage of the sludge may be required.

The advantages of sludge application to NFCC are:

- Solution to the "where to put it" question
- Recovery of P fertilizer value
- Recovery of N fertilizer value
- Recovery of soil conditioner value
- Elimination of ultimate disposal problem
- Elimination of incineration option
- Reduction of fertilizer use at comparable application costs (depending on option selected)

The disadvantages may be stated as listed below:

- Probable higher costs than commercial fertilizer for application options other than truck spreading
- Transport requirements and costs from POTW to site may be excessive
- Need different application schemes and equipment
- Potential "acceptability" problems by applicators.

The major advantage to using sewage sludge for the production of NFCC is probably related to the fact that sites for the land disposal of sewage sludges are difficult, if not impossible, to find near urban areas. This difficulty in finding suitable sites near urban areas occurs because the sludges are not recognized as a commodity of value by the general public. Thus, no community wants the disposal site located in its domain. However, using the sludges to produce crops may tend to elevate the sludges to a commodity of value; the disposal sites could become beneficial land management options and would be welcomed by communities as ways of preserving the country side/open spaces and reducing the potential for development. The use of sewage sludge for NFCC production may be found to be more acceptable to the general public and the crop production sites may be more easily obtained.

The major disadvantage to the production of NFCC using sewage sludge may be the sludge transport costs.

Determination of Land Requirements and Costs

Based on the annual N and P requirements for cotton, sod and biomass and the N and P content of sewage sludge, the annual sludge application rates necessary to satisfy the nutrient requirements of each crop were calculated. Given the quantity of sludge generated annually in each state or region of the United States and the sludge application rates determined above, the amount of land in each region that can be fertilized using all of the sludge produced annually in that region was then calculated. The costs of applying this sludge to the land by three modes of application were then determined and compared to the costs of applying commercial fertilizer at rates needed to satisfy crop nutrient requirements.

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Calculations used for determining sludge and fertilizer application rates and costs of using commercial fertilizer are presented below, followed by a description of the methods that were used for calculating costs of sludge application.

Application of Nitrogen to Crops --

Sewage sludge--The N content of most sewage sludges ranges from 2 to 3.3% (51) and 2.5% was assumed for this study. The total N in the sludge occurs in various forms, and about 30% to 40% of that is the available N. The sludge application rates were determined as given below:

1. N requirement for cotton: 45 to 135 kg/ha/yr (40 to 120 lb/acre/yr). An N value of 79 kg/ha/yr (70 lb/acre/yr) was assumed

$$\text{Sludge application rate} = \frac{79\ \text{kg/ha/yr}}{(0.35)(0.025\ \text{kg N/kg Sludge})} \times \frac{1\ \text{MT Sludge}}{1000\ \text{kg Sludge}}$$

$$= 9\ \text{DMT/ha/yr}\ (4\ \text{DT/acre/yr})$$

2. N requirement for sod: 191 kg/ha/yr (170 lb/acre/yr)

$$\text{Sludge application rate} = \frac{191\ \text{kg/ha/yr}}{(0.35)(0.025\ \text{kg N/kg Sludge})} \times \frac{1\ \text{MT Sludge}}{1000\ \text{kg Sludge}}$$

$$= 22\ \text{DMT/ha/yr}\ (10\ \text{DT/acre/yr})$$

3. N requirement for biomass crops: 112 kg/ha/yr (100 lb/acre/yr)

$$\text{Sludge application rate} = \frac{112\ \text{kg/ha/yr}}{(0.35)(0.025\ \text{kg N/kg sludge})} \times \frac{1\ \text{MT Sludge}}{1000\ \text{kg Sludge}}$$

$$= 13\ \text{DMT/ha/yr}\ (6\ \text{DT/acre/yr})$$

Commercial fertilizer--Aqueous ammonia, containing 30% NH_3, was used as the basic source of commercial N. The fertilizer application rates were determined as given below (all calculations are on a dry weight basis):

1. N requirement for cotton = 79 kg/ha/yr (70 lb/acre/yr)

$$\text{N in 30\% aqueous ammonia} = \frac{0.30\ \text{kg}\ NH_3\ (14/17)}{1\ \text{kg Fertilizer}} \times \frac{1000\ \text{kg Fertilizer}}{1\ \text{MT Fertilizer}}$$

$$= 247\ \text{kg N/1 MT Fertilizer}$$

$$\text{Fertilizer application rate} = \frac{79\ \text{kg/ha/yr}}{247\ \text{kg N/MT}}$$

$$= 0.32\ \text{MT/ha/yr}\ (0.14\ \text{DT/acre/yr})$$

Cost of aqueous ammonia fertilizer:

range = \$188 to \$198/MT (\$170 to \$180/ton)
use cost of = \$198/MT (\$180/ton)

Cost of spreading the fertilizer = \$7.41/ha (\$3.00/acre)
Cost of custom application = \$198/MT X 0.32 MT/ha/yr + \$7.41/ha
= \$71/ha (\$29/acre)

2. N requirement for sod = 191 kg/ha/yr
N in 30% aqueous ammonia = 247 kg N/MT Fertilizer
Fertilizer application rate = $\frac{191\ \text{kg/ha/yr}}{247\ \text{kg N/MT}}$
= 0.77 MT/ha/yr (0.35 DT/acre/yr)

Cost of aqueous ammonia fertilizer = \$198/MT (\$180/ton)
Cost of spreading the fertilizer = \$7.41/ha (\$3.00/acre)
Cost of custom application = \$198/MT X 0.77 MT/ha/yr + \$7.41/ha
= \$160/ha (\$65/acre)

3. N requirement for biomass crops = 112 kg/ha/yr (100 lb/acre/yr)
N in 30% aqueous ammonia = 300 kg N/MT Fertilizer
Fertilizer application rate = $\frac{112\ \text{kg/ha/yr}}{247\ \text{kg N/MT}}$
= 0.45 MT/ha/yr (0.20 DT/acre/yr)

Cost of aqueous ammonia fertilizer = \$198/MT (\$180/ton)
Cost of spreading the fertilizer = \$7.41/ha (\$3.00/acre)
Cost of custom application = \$198/MT X 0.45 MT/ha/yr + \$7.41/ha
= \$97/ha (\$39/acre)

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Application of Phosphorus to Crops--

Sewage sludge--The P content of most sewage sludge is about the same as that for N, and 2.5% was used for this study. The total P in the sludge occurs in various forms, and about 4.6% of that is available for crop utilization. The sludge application rates for P were determined as given below:

1. P requirement for cotton: 59 kg/ha/yr (53 lb/acre/yr)

$$\text{Sludge application rate} = \frac{59\ \text{kg/ha/yr}}{(0.46)(0.025\ \text{kg P/kg Sludge})} \times \frac{1\ \text{MT Sludge}}{1000\ \text{kg Sludge}}$$

$$= 5.17\ \text{DMT/ha/yr}\ (2.3\ \text{DT/acre/yr})$$

2. P requirement for sod: 52 kg/ha/yr (46 lb/acre/yr)

$$\text{Sludge application rate} = \frac{52\ \text{kg/ha/yr}}{(0.46)(0.025\ \text{kg/ P/kg Sludge})} \times \frac{1\ \text{MT Sludge}}{1000\ \text{kg Sludge}}$$

$$= 4.48\ \text{DMT/ha/yr}\ (2\ \text{DT/acre/yr})$$

3. P requirement for biomass crops: 92 kg/ha/yr (82 lb/acre/yr)

$$\text{Sludge application rate} = \frac{92\ \text{kg/ha/yr}}{(0.46)(0.025)\ \text{kg P/kg Sludge}} \times \frac{1\ \text{MT Sludge}}{1000\ \text{kg Sludge}}$$

$$= 8\ \text{DMT/ha/yr}\ (3.57\ \text{DT/acre/yr})$$

Commercial fertilizer--Phosphorus pentoxide containing 40% P was used as the basic source of P for application to crops. These fertilizer application rates were determined as given below:

1. P requirement for cotton = 59 kg/ha/yr (53 lb/acre/yr)

$$\text{P available in fertilizer} = \frac{0.40\ \text{kg P}}{1\ \text{kg Fertilizer}} \times \frac{1000\ \text{kg Fertilizer}}{1\ \text{MT Fertilizer}}$$

$$= 400\ \text{kg P/MT Fertilizer}$$

$$\text{Fertilizer application rate} = \frac{59\ \text{kg/ha/yr}}{400\ \text{kg P/MT}}$$

$$= 0.15\ \text{MT/ha/yr}\ (0.07\ \text{DT/acre/yr})$$

Cost of P_2O_5:

Range = \$1,345 to \$1,455/MT (\$1,220 to \$1,320/ton)
Use cost of \$1,455/MT
Cost of spreading the fertilizer = \$7.41/ha (\$3.00/acre)
Cost of custom application = \$1,455/MT X 0.15 MT/ha/yr + \$7.41/ha
= \$226/ha (\$91/acre)

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2. P requirement for sod = 52 kg/ha/yr (46 lb/acre/yr)
   P available in fertilizer = 400 kg P/MT Fertilizer
   Fertilizer application rate = $\frac{52 \text{ kg/ha/yr}}{400 \text{ kg P/MT}}$
   = 0.13 MT/ha/yr (0.06 DT/acre/yr)

   Cost of P_2O_5 = $1,455/MT

   Cost of spreading the fertilizer = $7.41/ha ($3.00/acre)
   Cost of custom application = $1,455/MT X 0.13 MT/ha/yr + $7.41/ha
   = $197/ha ($80/acre)

3. P requirement for biomass crops = 92 kg/ha/yr (82 lb/acre/yr)
   P available in fertilizer = 400 kg P/MT Fertilizer

   Fertilizer application rate = $\frac{92 \text{ kg/ha/yr}}{400 \text{ kg P/MT}}$

   = 0.23 MT/ha/yr (0.10 DT/acre/yr)

   Cost of P_2O_5 = $1,455/MT

   Cost of spreading the fertilizer = $7.41/ha ($3.00/acre)

   Cost of custom application = $1,455/MT X 0.23 MT/ha/yr + $7.41/ha
   = $342/ha ($138/acre)

Cost Estimates for Sludge Application--

Cost data used for this study were derived from existing sources in the literature.

Several conversations were held with project personnel related to how original cost estimates were constructed. The accuracy of cost estimates for sludge application is probably in the range of 50%. The estimates are probably high rather than low. This is the case because:

- Available cost data probably included a number of factors such as management, legal, site preparation, engineering, etc., which would be lower or non-existent for small systems.

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- Available data probably included some transport or sludge production costs (costs incurred at the POTW).

Figures 5, 6, and 7 show the data that were used for calculating unit sludge application costs. These figures show capital costs that have been updated to late 1979 costs using the ENR CCI of 3131, and operation and maintenance costs that have been updated using the October 1979 Consumer Price Index of 226. Capital costs in these figures include land costs. To arrive at the capital cost values in Tables 22 through 27, land costs, assumed at $3,706/ha ($1,500/acre), were deducted from capital costs indicated on Figures 5, 6 and 7; this difference was then amortized at 7 1/8% for 5 years. Operation and maintenance costs were read directly from the figures. Total annual costs represent the sum of the capital costs and the O&M costs.

CASE STUDY 1: COTTON PRODUCTION

Land Requirements

The average annual nutrient requirements for cotton are 79 kg/ha (70 lbs/acre) of N, 59 kg/ha (53 lbs/acre) of P as P_2O_5 and 70 kg/ha (62 lbs/acre) of K as K_2O (51). Liquid sludge application to cotton croplands, in order to satisfy the N and P requirements of the crop, requires that the sludge be applied at an average rate of 9 DMT/ha/yr (4 DT/acre/yr) for N and 5.17 DMT/ha/yr (2.3 DT/acre/yr) for P. The hectares of land needed in each of the cotton producing states to utilize the sludge generated in those states was determined by dividing the quantity of sludge generated in the state by the average annual loading rate. In most cases, as shown on Tables 22 and 23, the amount of land required to utilize all of the sludge produced in each state ("Land fertilized") is less than the land that is currently being harvested for cotton in that state ("Land harvested"). In Florida, Kentucky and Nevada, the land needed to utilize all of the sludge in each of those states exceds the land currently being harvested for cotton. In these three states, then, only a fraction of the sludge generated could be used for producing cotton. For example, in Florida,

sludge generated = 160,801 DMT/yr (177,250 DT/yr)

land under cultivation for cotton production = 2,873 ha (7,099 acres)

amount of land area needed if all the sludge generated in that state was used

$$= \frac{160{,}801 \text{ DMT/yr}}{9 \text{ DMT/ha/yr}}$$

$$= 17{,}867 \text{ ha } (44{,}149 \text{ acres})$$

quantity of sludge that could be used in Florida for cotton production, based on N, = 2,873 ha x 9 DMT/ha/yr

$$= 25{,}857 \text{ DMT/yr}$$

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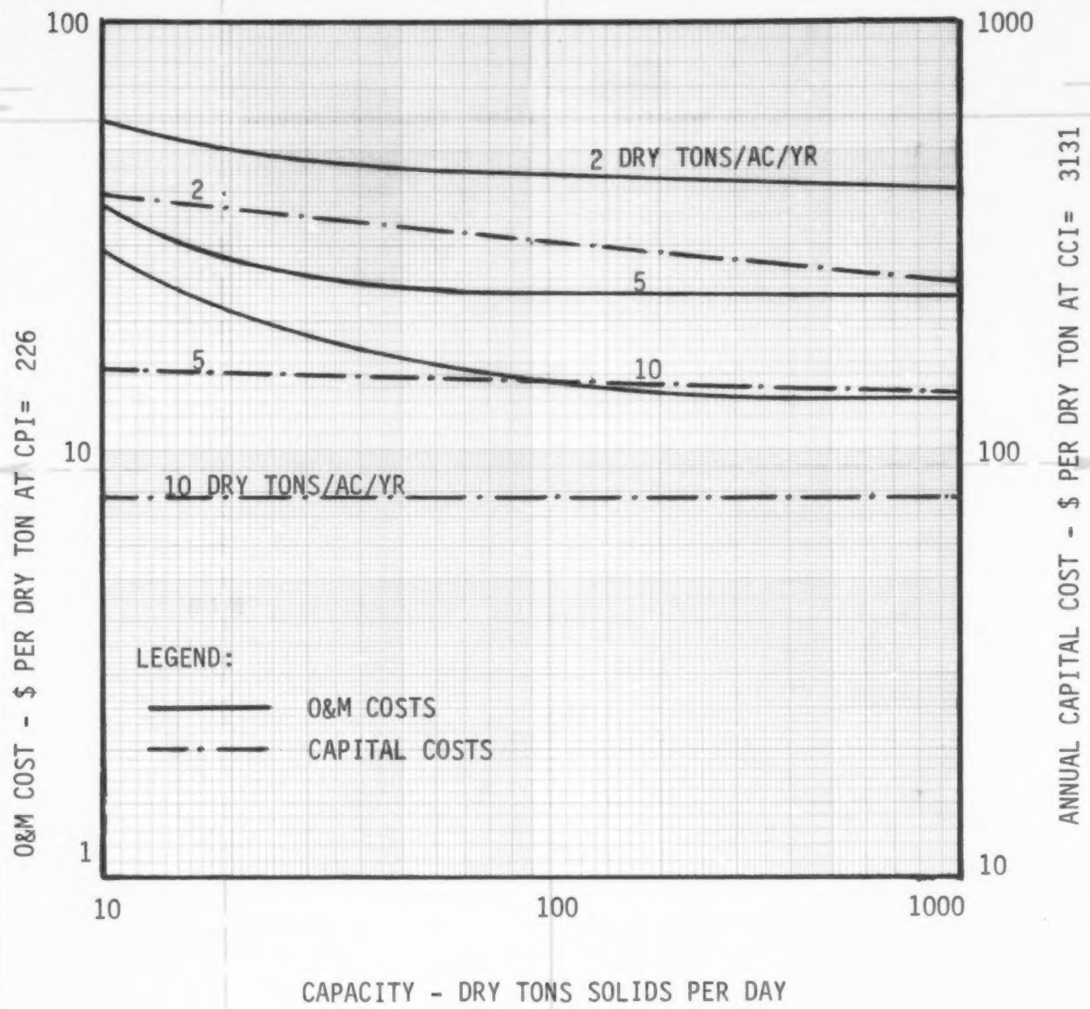

ENGINEERING NEWS RECORD:
CCI - CONSTRUCTION COST INDEX = 3131, OCTOBER 1979 (1913=100)
U.S. DEPT. OF COMMERCE:
CPI - CONSUMER PRICE INDEX = 226, OCTOBER 1979
DRY TONS (SHORT) x 0.9072 = DRY TONS (METRIC)

Figure 5. Costs of land application of sludge by injection.

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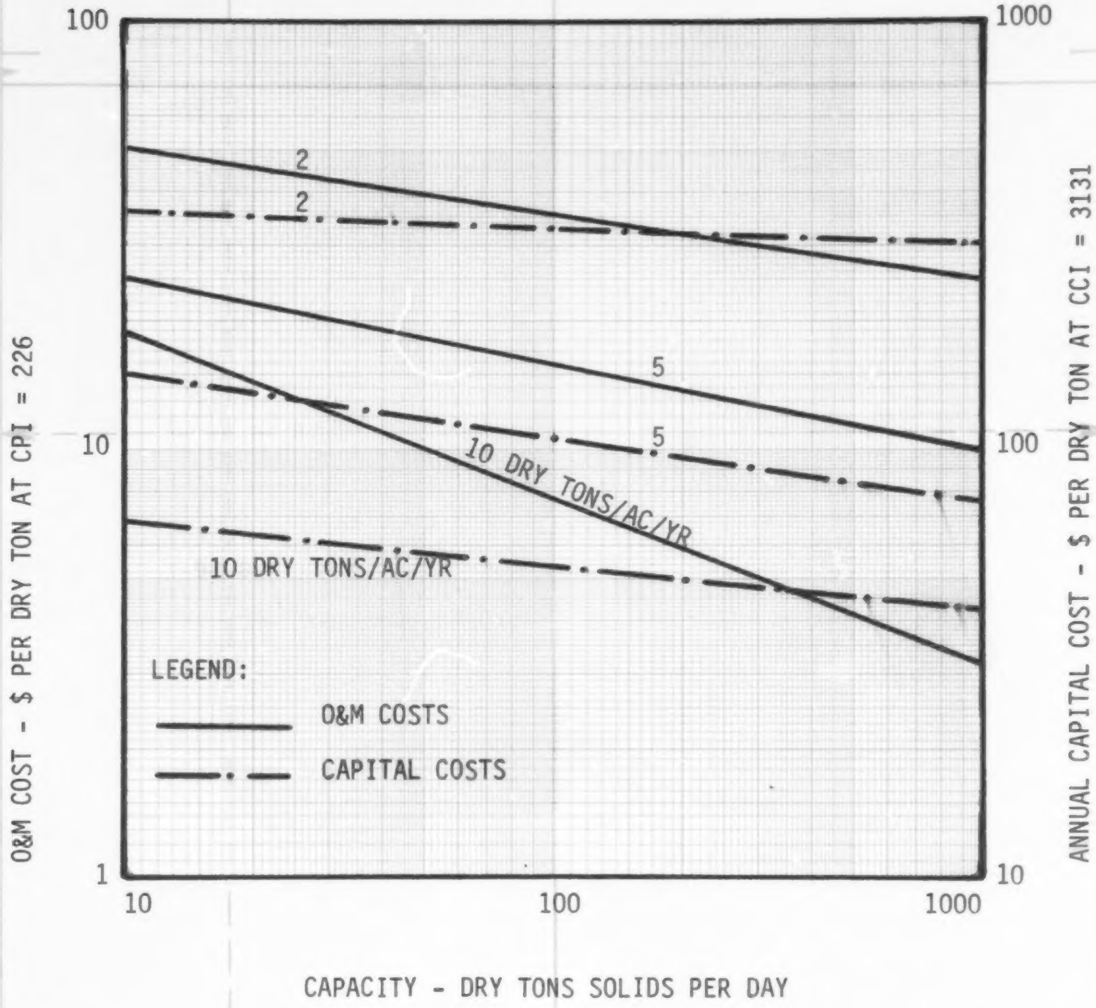

ENGINEERING NEWS RECORD:
CCI - CONSTRUCTION COST INDEX = 3131, OCTOBER 1979 (1913=100)
U.S. DEPT. OF COMMERCE:
CPI - CONSUMER PRICE INDEX = 226, OCTOBER 1979
DRY TONS (SHORT) x 0.9072 = DRY TONS (METRIC)

Figure 6. Costs of sludge application by surface irrigation.

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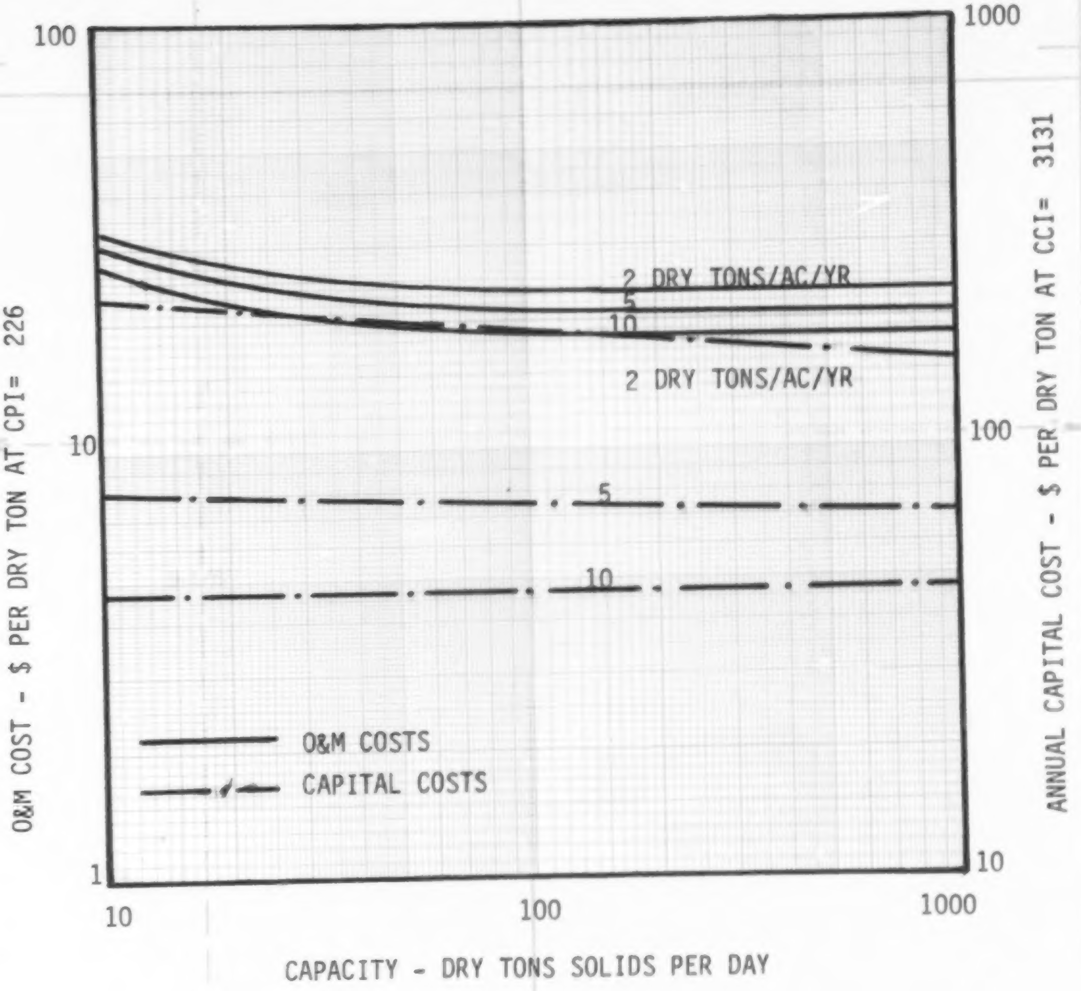

ENGINEERING NEWS RECORD:
  CCI - CONSTRUCTION COST INDEX = 3131, OCTOBER 1979 (1913=100)
U.S. DEPT. OF COMMERCE:
  CPI - CONSUMER PRICE INDEX = 226, OCTOBER 1979
DRY TONS (SHORT) x 0.9072 = DRY TONS (METRIC)

Figure 7. Costs of truck-spreading liquid sludge.

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TABLE 22. COST OF APPLYING LIQUID SLUDGE TO PROVIDE NITROGEN FOR COTTON CULTIVATION

State	Sludge generated 1977 (DMT/Yr)	Land harvested (ha)	Sludge required (DMT/Yr)	Land fertilized (ha)	Injection				Surface irrigation				Truck spread				Aqueous Ammonia 30% NH_3 ($/ha)
					Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	
Ala.	90,500	169,976	90,500	10,093	94	31	125	1,121	52	19	71	637	7	23	30	269	71
Ariz.	34,800	137,600	34,800	3,881	111	32	143	1,283	58	23	81	727	11	23	34	305	71
Ark.	20,800	384,470	20,800	2,320	118	32	150	1,345	65	26	91	816	14	24	38	341	71
Calif.	428,503	453,270	428,503	47,789	82	29	111	996	41	14	55	493	2	22	24	215	71
Fla.*	160,801																
	(25,761)	2,873	25,761	2,873	118	32	150	1,346	63	25	88	789	13	23	36	323	71
Ga.	137,201	97,129	137,201	15,301	87	31	118	1,058	47	18	65	583	6	23	29	260	71
Ky.*	53,293																
	(4,717)	526	4,717	526	134	44	178	1,597	77	36	113	1,014	18	30	48	431	71
La.	40,000	226,635	40,000	4,461	108	32	140	1,256	58	23	81	727	9	23	32	287	71
Miss.	54,201	594,917	54,201	6,045	103	32	135	1,211	57	21	78	700	9	23	32	287	71
Mo.	72,000	105,224	72,000	8,030	97	31	128	1,148	54	20	74	664	8	23	31	278	71
Nev.*	18,300																
	(3,992)	445	3,992	445	139	46	185	1,659	80	37	117	1,049	22	31	53	475	71
N.M.	21,000	25,901	21,000	2,342	118	32	150	1,345	65	26	91	816	13	24	37	332	71
N.C.	107,701	28,734	107,701	12,011	93	31	124	1,112	50	19	69	619	6	23	29	260	71
Okla.	47,100	135,576	47,100	5,253	105	32	137	1,229	58	22	80	718	9	23	42	287	71
S.C.	79,801	64,348	79,801	8,900	96	31	127	1,139	53	20	73	655	7	23	30	269	71
Tenn.	126,801	149,741	126,801	14,141	93	31	124	1,112	47	19	66	592	6	23	29	260	71
Tex.	301,502	182,117	301,502	33,625	86	31	117	1,049	42	15	57	511	2	23	25	224	71
Va.	94,701	242,003	94,701	10,561	94	31	125	1,121	52	19	71	637	6	23	29	260	71

Sludge application rate: 8.97 DMT/ha/yr (4.0 DT/acre/yr)
Fertilizer application rate: 0.32 MT/ha/yr (0.14 DT/acre/yr)
*Number in bracket is sludge quantity that can be used.

TABLE 23. COST OF APPLYING LIQUID SLUDGE TO PROVIDE PHOSPHORUS FOR COTTON CULTIVATION

State	Sludge generated 1977 (DMT/Yr)	Land harvested (ha)	Sludge required (DMT/Yr)	Land fertilized (ha)	Injection				Surface irrigation				Truck spread				P_2O_5 40% P ($/ha)
					Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	
Ala.	90,500	159,976	90,500	17,553	123	47	170	879	164	34	198	1,024	19	25	44	227	226
Ariz.	34,800	137,600	34,800	6,750	163	48	211	1,091	187	40	227	1,174	32	26	58	300	226
Ark.	20,800	384,470	20,800	4,034	179	51	230	1,189	191	43	234	1,210	42	26	68	352	226
Calif.	428,503	453,270	428,503	83,110	88	43	131	677	157	25	182	941	7	25	32	165	226
Fla.*	160,801																
	(14,813)	2,873	14,813	2,873	189	51	240	1,241	198	45	243	1,256	48	27	75	388	226
Ga.	137,201	97,129	137,201	26,611	98	46	144	744	164	32	196	1,013	10	25	35	181	226
Ky.*	53,293																
	(2,712)	526	2,712	526	241	68	309	1,597	214	60	274	1,417	68	39	107	5535	226
La.	40,000	226,635	40,000	7,758	156	48	204	1,055	181	39	220	1,137	32	25	57	295	226
Miss.	54,201	594,917	54,201	10,512	146	48	194	1,003	178	37	215	1,111	27	25	52	269	226
Mo.	72,000	105,224	72,000	13,965	138	48	186	962	172	35	207	1,070	21	25	46	238	226
Nev.*	18,300																
	(2,295)	445	2,295	445	275	69	344	1,778	232	62	294	1,520	69	42	111	574	226
N.M.	21,000	25,901	21,000	4,073	175	51	226	1,168	191	43	234	1,210	42	26	68	352	226
N.C.	107,701	28,734	107,701	20,889	120	46	166	858	164	34	198	1,024	15	25	40	207	226
Okla.	47,100	135,576	47,100	9,135	153	48	201	1,034	179	38	217	1,122	27	25	52	269	226
S.C.	79,801	64,348	79,801	15,478	135	48	183	946	171	35	206	1,065	21	25	46	238	226
Tenn.	126,801	149,741	126,801	24,594	115	46	161	832	164	33	197	1,018	13	25	38	196	226
Tex.	301,502	182,117	301,502	58,441	93	44	137	708	158	29	187	967	7	25	32	165	226
Va.	94,701	242,003	94,701	18,368	123	47	170	879	164	34	198	1,024	18	25	43	222	226

Sludge application rate: 5.17 DMT/ha/yr (2.3 DT/acre/yr)
Fertilizer application rate: 0.15 MT/ha/yr (0.07 DT/acre/yr)
*Number in bracket is sludge quantity that can be used.

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Therefore, 16% of the sludge generated in Florida could be used to supply the N needed for the total annual cotton production in that state.

For the states of Kentucky and Nevada, 9% and 22%, respectively of the sewage sludge generated in those states could be used to supply N to all of the land under cultivation for cotton production.

For the rest of the cotton producing states, the amount of sludge generated was not enough to supply the necessary N and P for cotton production. If all of the sludge generated by each of these states were used to supply N, the amount of cotton land that could be fertilized in each state ranges from 0.6% to 42% with the majority of the states generating enough sludge to supply less than 15% of the cotton lands in each state with sufficient N.

In the case of sludge utilization for the application of P to cotton cropland, again only Florida, Kentucky and Nevada would fall short in utilizing all of the sludge generated in their respective states. For the rest of the cotton producing states, all of the sludge generated by state could be used to supply P. The amount of cotton land in each state that could be fertilized using all of the sludge generated by state ranges from 0.5% to 73%. The majority of the states generate enough sludge to supply less than 20% of the cotton lands in each state with sufficient P.

Cost/Benefit Analysis

The costs for applying liquid sludge to provide N and P for cotton cultivation are given in Tables 22 and 23, respectively. Costs were computed for the injection, surface irrigation and truck spread modes of application. The costs for custom application of aqueous ammonia and 40% P as P_2O_5 are also given for cost comparisons. The cost of the sludge is taken as zero for this study. The costs for custom application include the cost of the fertilizer, the cost of shipping to the central outlet and the cost of application, but not transport to the site. A more detailed discussion of the types of factors considered is presented in Section 8.

The figures in Tables 22 and 23 indicate that utilizing sewage sludge to provide for cotton cultivation can in some cases be economically competitive with custom application of commercial phosphorus pentoxide fertilizer if the sludge is applied via truck spreading. Note that this is true only for the states fertilizing relatively large quantities of land with sewage sludge. In this case, the economies of scale associated with larger sludge projects (excluding land costs) are such that truck spreading of sludge may be an attractive alternative for supplying P to cotton compared to commercial fertilizer applications.

All other modes for the application of liquid sludge to supply N or P are 3 to 23 times the costs for custom application for N or P. It should be remembered, however, that when sludge is applied to provide N or P, the automatic addition of P or N could be an added benefit at no cost to the user. The additional benefits to be gained are as follows:

1. A reduction in the energy consumed for the production of commercial fertilizers as discussed in Section 4,
2. An improvement in the soil due to the soil conditioner attributes in the sludge,
3. The reclamation of spent or abused lands unable to produce quality crops without the addition of soil ammendments and other necessary soil nutrients, all of which are provided by the sludge, and
4. The beneficial use of a valuable resource-sewage sludge.

CASE STUDY 2: SOD PRODUCTION

Land Requirements

Most lawns require about 8 kg (17 lbs) of processed sewage sludge, or 23 kg (50 lbs) of liquid sewage sludge per 93 M^2 (1,000 ft^2) once or twice a year. In order to satisfy the N and P requirements of sod, liquid sludge must be applied at an average annual rate of 22 DMT/ha/yr (10 DT/acre/yr) to supply the necessary N and 4.48 DMT/ha/yr (2 DT/acre/yr) to supply the necessary P.

Again, the quantity of land needed to utilize all of the sludge produced in each state was calculated by dividing the sludge generated in each state (Tables 24 and 25) by the above sludge application rates for sod. In Florida and Delaware, this land requirement to use all of the sludge to provide nitrogen for sod is lower than the land currently harvested for sod; thus all of the sludge could be used. The quantity of land that could be fertilized (based on nitrogen) using all of the sludge in each state amounts to 86% and 62% of the land currently under harvest for sod in Delaware and Florida, respectively.

In all other cases, the quantity of land needed to utilize all of the sludge generated was found to exceed the quantity of land being harvested for sod in each state. The amount of land that can be fertilized is thus constrained by the amount of land currently harvested rather than by the quantity of sludge available for application. In Tables 24 and 25, then (with the two exceptions noted above), "Land fertilized" is equal to "Land harvested", and "Sludge required" is determined by multiplying the quantity of land fertilized by the annual sludge application rate. In most cases, then, the amount of sludge generated in the sod producing states is more than that which can be utilized for producing the crop. The amount of sludge that can be used for providing nitrogen for sod ranges from 4% to 100% of the sludge produced in the respective states. To provide phosphorus, only 1.4% to 33% of the sludge produced could be used.

Cost/Benefit Analysis

The costs for applying liquid sludge to provide N and P for sod production are given in Tables 24 and 25, respectively. The methodology used for the cotton case study is the same as used here. As with cotton, with the exception of applying sludge to provide P for sod via truck spreading, the cost of custom application using commercial fertilizer for supplying N and P

TABLE 24. COST OF APPLYING LIQUID SLUDGE TO PROVIDE NITROGEN FOR SOD CULTIVATION

State	Sludge generated 1977	Land harvested	Sludge required	Land fertilized	Injection				Surface irrigation				Truck spread				Aqueous Ammonia 30% NH_3
					Cap.	O&M	Total		Cap.	O&M	Total		Cap.	O&M	Total		
	(DMT/Yr)	(ha)	(DMT/Yr)	(ha)	($/DMT)	($/DMT)	$/DMT	$/ha	($/DMT)	($/DMT)	$/DMT	$/ha	($/DMT)	($/DMT)	$/DMT	$/ha	($/ha)
Ohio	367,703	1,416	31,152	1,416	45	15	60	1,320	20	9	29	638	11	20	31	682	160
Ind.	160,001	809	17,798	809	45	18	63	1,386	21	11	32	704	11	22	33	726	160
Ill.	530,704	1,619	35,618	1,619	45	15	60	1,320	19	8	27	594	11	20	31	682	160
Mich.	336,702	2,428	53,416	2,428	45	15	60	1,320	16	7	23	506	11	19	30	660	160
Wisc.	149,901	1,214	26,708	1,214	45	16	61	1,342	20	10	30	660	11	21	32	704	160
Minn.	162,001	2,104	46,288	2,104	45	15	60	1,320	17	8	25	550	11	19	30	660	160
Iowa	63,701	607	13,354	607	45	20	67	1,474	23	12	35	770	11	23	34	748	160
Miss.	72,001	405	8,910	405	45	21	66	1,452	26	14	40	880	11	24	35	770	160
Nebr.	27,400	486	10,692	486	45	21	66	1,452	26	13	39	858	11	23	34	748	160
Kans.	38,700	809	17,798	809	45	18	63	1,386	21	11	32	704	11	22	33	726	160
Del.	26,900	1,416	26,900	1,223	45	16	61	1,342	20	10	30	660	11	21	32	704	160
Ga.	137,201	809	17,798	809	45	18	63	1,386	21	11	32	704	11	22	33	726	160
Fla.	160,801	11,736	160,801	7,309	45	14	59	1,298	11	4	15	330	11	19	30	660	160
Tex.	301,502	1,214	26,708	1,214	45	17	62	1,364	20	10	30	660	11	21	32	704	160
Ala.	90,500	526	11,572	526	45	20	65	1,430	25	13	38	836	11	23	34	748	160
Conn.	81,900	1,693	37,246	1,693	45	15	60	1,320	19	8	27	594	11	20	31	682	160
N.Y.	537,103	971	21,362	971	45	17	62	1,364	21	10	31	682	11	21	32	704	160
N.J.	216,002	971	21,362	971	45	17	62	1,364	21	10	31	682	11	21	32	704	160
Calif.	428,703	809	17,798	809	45	18	63	1,386	21	11	32	704	11	22	33	726	160

Sludge application rate = 22 DMT/ha/yr (9.8 DT/acre/yr)
Fertilizer application rate = 0.77 MT/ha/yr (0.34 DT/acre/yr)

TABLE 25. COST OF APPLYING LIQUID SLUDGE TO PROVIDE PHOSPHORUS FOR SOD CULTIVATION

State	Sludge generated 1977 (DMT/Yr)	Land harvested (ha)	Sludge required (DMT/Yr)	Land fertilized (ha)	Injection				Surface irrigation				Truck spread				P_2O_5 40% P ($/ha)
					Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	
Ohio	367,703	1,416	6,349	1,416	185	56	241	1,080	177	51	228	1,021	37	31	68	305	197
Ind.	160,001	809	3,627	809	214	63	277	1,241	184	55	239	1,071	48	35	83	372	197
Ill.	530,704	1,619	7,258	1,619	185	55	240	1,075	177	50	227	1,017	37	31	68	305	197
Mich.	336,702	2,428	10,886	2,428	175	53	228	1,021	165	47	212	950	27	29	56	251	197
Wisc.	149,901	1,214	5,443	1,214	191	59	250	1,120	180	53	233	1,044	45	33	78	349	197
Minn.	162,001	2,104	9,426	2,104	176	53	229	1,026	165	48	213	954	30	29	59	264	197
Iowa	63,701	607	2,719	607	216	68	284	1,272	186	60	246	1,102	48	40	88	394	197
Miss.	72,001	405	1,814	405	218	84	302	1,353	195	66	261	1,169	50	49	99	444	197
Nebr.	27,400	486	2,177	486	218	73	291	1,304	195	62	257	1,151	48	42	90	403	197
Kans.	38,700	809	3,624	809	214	63	277	1,241	184	55	239	1,071	48	35	83	372	197
Del.	26,900	1,376	6,164	1,376	185	56	241	1,080	180	51	231	1,035	37	31	68	305	197
Ga.	137,201	809	3,624	809	214	63	277	1,241	184	55	239	1,071	48	35	83	372	197
Fla.	160,801	11,736	52,577	11,736	125	47	172	771	153	37	190	851	2	25	27	121	197
Tex.	301,502	1,214	5,439	1,214	191	59	250	1,120	180	53	233	1,044	45	33	78	349	197
Ala.	90,500	526	2,356	526	216	73	289	1,295	190	62	252	1,129	48	42	90	403	197
Conn.	81,900	1,673	7,501	1,673	185	55	240	1,075	177	50	227	1,017	37	30	67	300	197
N.Y.	537,103	971	4,353	971	204	61	265	1,187	182	54	236	1,057	45	34	79	353	197
N.J.	216,002	971	4,353	971	295	61	356	1,595	213	54	267	1,196	81	34	115	515	197
Calif.	428,703	809	3,627	809	214	63	277	1,241	184	55	239	1,071	48	35	83	372	197

Sludge application rate = 4.48 DMT/ha/yr (2.0 DT/acre/yr)
Fertilizer application rate = 0.13 MT/ha/yr (0.06 DT/acre/yr)

is 2 to 9 times cheaper than the costs incurred if sewage sludges were used to supply the nutrient. High costs are probably attributable to the small amounts of land under crop cultivation. Truck spreading of sludge to provide phosphorus appears to be actually cheaper than fertilizer application only in Florida, due to the economy of scale associated with applying sludge to the larger land area that can fertilized in this state. In all other states, truck spreading of sludge to supply P is more expensive than utilizing commercial fertilizers although the associated costs are more competitive than the other application modes for either nutrient. The cost of the sludge was assumed to be no cost to the user. The additional benefits are the same as for cotton.

CASE STUDY 3: BIOMASS PRODUCTION

Land Requirements

Table 17 gives the various fertilizer and sewage sludge application rates that have been used or recommended by many researchers for the production of this crop. For this study sewage sludge application rates of 13.45 DMT/ha/yr (6 DT/acre/yr) for N and 7.85 DMT/ha/yr (3.5 DT/acre/yr) for P were used.

The land available for crop production was more than that needed to utilize all the sludge generated in the biomass producing states. As shown in Tables 26 and 27, all the sludge generated in those regions or states could be used to produce these crops. The land area to be fertilized was determined by dividing the amount of sludge generated in the region or state by the sludge loading rates. For example, for the northeast region,

annual sludge generation = 1,556,010 MT/yr

applicate rate for N, = 13.450 MT/ha/yr

Therefore, the land area that could be fertilized using sewage sludge, based on N is,

$$\frac{1{,}556{,}010 \text{ MT/yr}}{13.450 \text{ MT/ha/yr}} = 115{,}689 \text{ ha}$$

Thus, if all the sewage sludge generated in the northeast were used to supply N to the soil for biomass crop production, only 10% of the land that could be dedicated for this crop would be involved.

The hectares of land that could be fertilized in each region using all of the sewage sludge generated in those regions for biomass production ranges from 0.6% to 22%. If biomass production were undertaken in the form of biomass plantations (monoculture operations), this would be an excellent crop for production using sewage sewage.

Cost/Benefit Analysis

The costs for applying liquid sludge to provide N and P for biomass production are given in Tables 26 and 27, respectively. Applying sludge via surface irrigation and truck spreading is shown in these tables to be cheaper than applying sludge by injection for both nutrients, although the difference is more pronounced in the case of N. None of the sludge application modes to provide nitrogen are competitive with applying commercial fertilizer, ranging from 1.25 to 13 times more expensive. For phosphorus, the values presented in Table 27 indicate that the costs of sludge application via surface irrigation and truck spreading can in many cases be cheaper than, or in the range of, costs for applying commercial fertilizer. Again, this is the case mainly in the regions fertilizing large quantities of land, due to the associated economies of scale. This is due also to the high costs associated with using commercial P fertilizer.

SUMMARY

For the three crops considered, the utilization of sewage sludge to supply nutrients for the production of cotton and biomass crops does offer a significant beneficial sludge use option. However, utilization of sludge for sod production is the most feasible at this time. Sod production would utilize, conservatively, 5% to 10% of the total sludge generated in the sod producing states. This may represent a significant sludge use option and should be pursued to the fullest extent possible. Most of the research on biomass cultivation has not involved the use of sewage sludge to provide N and P and for soil conditioning. Research on the use of sewage sludge (and even sewage effluent) as a substitute for commercial fertilizers for the production of this crop should be encouraged by the sponsoring agency or institution. Additionally, because of the fast rotation periods being investigated, the use of sewage sludge would offer additional benefits in terms of its soil conditioner values. While most of the cotton being produced is used in part for food chain products, the possibility does exist whereby a portion of this crop could be grown for non-food-chain purposes only. This crop and the soil on which it is cultivated would respond favorably to sewage sludge applications.

It is evident from the above case studies that all of the sewage sludge generated cannot be used for the production of NFCC. However, based on just the three crops presented here, at least 20% of the total sludge generated could be used for those crops. That is significant. The problem of more sludge generated than is required for application raises other concerns such as the need for sludge storage facilities and the need for other beneficial sludge use options. These "needs" should be addressed if the eventual objective is to use and to recycle sewage sludge as much as possible.

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TABLE 26. COST OF APPLYING LIQUID SLUDGE TO PROVIDE NITROGEN FOR BIOMASS CULTIVATION

Region	Sludge generated 1977 (DMT/Yr)	Land harvested (ha)	Sludge required (DMT/Yr)	Land fertilized (ha)	Injection				Surface irrigation				Truck spread				Aqueous Ammonia 30% NH_3 ($/ha)
					Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	
North East (Md.,N.J., N.Y.)	1,536,010	1,173,646	4,639	115,689	60	22	82	1,103	2	7	9	121	5	22	27	363	97
Mid-Atlantic (W.Va., Va., N.C.,Tenn., Ky.)	464,103	1,456,940	1,402	34,506	65	23	88	1,184	9	9	18	242	9	23	32	430	97
South East (S.C.,Ga.,Ala., Fla.)	468,303	2,063,998	1,414	34,818	64	23	87	1,170	9	9	18	242	9	23	32	430	97
South Gulf (La.,Miss., Ark.)	115,001	1,416,469	347	8,550	74	24	98	1,318	18	11	29	390	11	24	35	471	97
South Central (Tex.,Okla.)	348,602	1,699,763	1,053	25,919	67	23	90	1,211	10	9	19	255	9	23	32	430	97
Central (Iowa.,Mo., Ill.,Ind., Ohio)	1,194,208	1,133,175	3,606	88,789	60	22	82	1,103	4	8	12	161	6	22	28	377	97
Great Lakes (Minn.,Wisc., Mich.)	648,604	1,335,528	1,959	48,224	63	23	86	1,157	6	8	14	188	7	23	30	403	97
Mid-West (N.D.,S.D., Nebr., Kans.)	74,701	242,823	226	5,554	74	24	98	1,318	20	12	32	430	13	24	37	498	97
West (Wash.,Oreg., Calif.)	600,203	202,353	1,813	44,625	64	23	87	1,170	7	9	16	215	7	23	30	403	97

Sludge application rate: 13.45 DMT/ha/yr (6 DT/acre/yr)
Fertilizer application rate: 0.45 MT/ha/yr (0.20 DT/acre/yr)

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TABLE 27. COST OF APPLYING LIQUID SLUDGE TO PROVIDE PHOSPHORUS FOR BIOMASS CULTIVATION

Region	Sludge generated 1977 (DMT/Yr)	Land harvested (ha)	Sludge required (DMT/Yr)	Land fertilized (ha)	Injection				Surface irrigation				Truck spread				P_2O_5 40% P ($/ha)
					Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	Cap. ($/DMT)	O&M ($/DMT)	Total $/DMT	Total $/ha	
North East (Md.,N.J., N.Y.)	1,536,010	1,173,646	1,536,010	198,321	43	31	74	581	30	11	41	322	14	23	37	290	342
Mid-Atlantic (W.Va., Va., N.C.,Tenn., Ky.)	464,103	1,456,940	464,103	59,153	64	31	95	746	32	13	45	353	18	24	42	330	342
South East (S.C.,Ga.,Ala., Fla.)	468,303	2,063,998	468,303	59,688	64	31	95	746	32	13	45	353	18	24	42	330	342
South Gulf (La.,Miss., Ark.)	115,001	1,416,469	115,001	14,658	81	32	113	887	34	19	53	416	25	24	49	385	342
South Central (Tex.,Okla.)	348,602	1,699,763	348,602	44,432	64	31	95	746	32	14	46	361	18	24	42	330	342
Central (Iowa.,Mo., Ill.,Ind., Ohio)	1,194,208	1,133,175	1,194,208	152,210	49	31	80	628	30	12	42	330	16	23	39	306	342
Great Lakes (Minn.,Wisc., Mich.)	648,604	1,335,528	648,604	82,669	62	31	93	730	30	12	42	330	17	24	41	322	342
Mid-West (N.D.,S.D., Nebr., Kans.)	74,701	242,823	74,701	9,521	85	33	118	926	35	20	55	432	26	25	51	400	342
West (Wash.,Oreg., Calif.)	600,203	202,353	600,203	76,500	64	31	95	746	31	13	44	345	17	24	41	322	342

Sludge application rate: 7.85 DMT/ha/yr (3.5 DT/acre/yr)
Fertilizer application rate: 0.23 MT/ha/yr (0.10 DT/acre/yr)

SECTION 8

COST ANALYSIS

BACKGROUND

It is desirable to compare the cost of the use of sludge for its nutrient and soil conditioner values with the cost of commercial fertilizer. In making such a comparison, however, a number of important factors which are related to each (fertilizer and sludge) make comparisons difficult.

A straightforward cost comparison approach would consist of determining the following:

Fertilizer	Sludge
A. Cost of fertilizer	A. Cost of sludge
B. Cost of transportation	B. Cost of transportation
C. Cost of application	C. Cost of application

In the case of fertilizer, the cost of fertilizer purchased at an outlet by a farmer includes the cost of production, transportation and profit. The farmer must then transport the fertilizer to the location of interest and apply it. Services are available to transport and apply fertilizer for farmers. For example, the Southern States Cooperative will provide such a service to the farmer at a cost. For the purposes of analysis during this study, the current cost of fertilizer was determined from the chemical marketing literature (62), and the costs of transport and application (custom application) were determined based on information from companies which provide that service and from the literature (63).

In the case of sludge, a determination of the cost factors was much more complex. Since sludge is not in common use for application to crops, even NFCC, and is not considered to be a "commodity", it was difficult to consider the cost of the sludge as recoverable. The cost of sludge, therefore, for any applications to NFCC over the near term future should probably be considered zero. This means that the cost of sludge production should be totally allocated to the cost of wastewater handling, treatment and disposal. There is a significant cost associated with the production of sludge. Total costs may amount to one-half of the sewage treatment expenditures on a total annual cost basis at a typical sewage treatment plant.

It is difficult, if not impossible, to determine sludge handling, dewatering and disposal costs accurately because of the many different accounting systems which are currently in use by POTW operating authorities. The

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cost to the consumer, however, may be widely different from the cost of actual production. The price is often kept low in an attempt to get rid of excess quantities. For example, the December 1979 cost of sludge was $4.52 per MT ($4.10/ton) F.O.B. Chicago (62). At this price, even if the cost of sludge is included in this analysis, it is a small percentage of the combined sludge transport and application cost.

Also, costs for various alternatives for sludge handling and disposal are often presented in the most favorable light depending on which option is being promoted. Even in the cases where costs have been assembled and analyzed with reasonable diligence, it is difficult to separate costs of sludge production from the costs of sludge transport and application to the land.

For the purposes of this study, various sludge disposal experiences involving application to the land in the U.S. were analyzed. Data were available from Chicago, Los Angeles/Orange County Metropolitan Area (LA/OMA), San Francisco and elsewhere (64, 65, 66, 67). It appeared that the San Francisco study had included the results of previous studies and was a summary in itself. It was, therefore, used as a primary reference for this work.

Based on a review of the cost data, it was difficult to determine what had been included in capital costs and the operating and maintenance costs. Trucks for transport, for example, might have been included in the capital cost or a leasing assumption might have been made. For any sludge application venture, site preparation costs for storage areas and a cost for the operation and maintenance of storage facilities should be included. This was uncertain in some of the reports.

It was also difficult to determine the lifetimes of spreading, storage and sludge moving equipment at the site because of a general lack of long-term experience in the U.S. Lifetimes used for annualizing costs for such equipment ranged from 5 to 20 years. Transportation requirements for sludge are fixed in that the sludge must be moved from generating points at sewage treatment plants to points of application which may be long distances away. Fertilizer sales operations, on the other hand, will normally be located centrally for potential use by the farmers. Also, the costs of fertilizer "off the shelf" at the outlet already include some transportation costs (probably by train from the point of manufacture to the point of distribution).

The application of sludge to crops - even NFCC which require longer growing periods - is likely to be seasonal. Weather conditions will be the most prominent constraint throughout the northern and Plains states. Changes may, therefore, be required at the POTW in order to accommodate the large scale application of sludge to NFCC. Because of pick-up schedules, storage facilities may be required. Because of application techniques and equipment, it may be desirable to produce sludge with varying water composition in order to facilitate application during different times of the year and/or for different crop types.

There are other considerations which complicate the cost comparison picture. A farmer buys commercial fertilizer on the basis of NPK content. Sludge, on the other hand, will provide N, some P and very little K. The cost of augmenting sludge with additional K was not considered in this study. The types of equipment used to apply commercial fertilizer versus that required to apply sludge may be different for terrain, crop type and weather conditions.

In the case of application of sludge to NFCC, it may be possible to consider the application of sludge to accelerate growth conditions in cases where no commercial fertilizer is currently being applied.

Because of the foregoing considerations and others, it was not possible, based on currently existing data and information, to fully draw comparisons between current commercial fertilizer costs and expected costs for sludge application. The determination of accurate costs for sludge application alternatives is clearly an area for further research and development effort, and if ventures are to be successful and alternatives made believable, such further work should be done in the near future.

A cost comparison has been developed and the information is presented under various conditions in order to perform a sensitivity analysis and provide the reader with a general idea of how costs might vary depending on various conditions.

DISCUSSION AND SUMMARY

Sludge Application Costs Comparisons

It must be emphasized that applying the sludge based on the N content will simultaneously supply the soil with more P than the crop needs. For most crops this will probably not be a problem. However, several crops (soybeans and possibly the Douglas fir) have shown a decrease in growth due to phosphorus phytotoxicity. Thus, the application of the sludge based on P might be preferable if phosphorus phytotoxicity is suspected of being a concern. The N requirements for the crop will not be sufficient, if sludge is applied based on P. The N in the soil might be sufficient, or supplemental N in the form of commercial fertilizer might have to be added.

Table 28 summarizes the total annual cost (O&M plus annualized capital cost) for sludge application to the three selected crops. The costs are presented based on supplying required quantities of N and P in each case; costs for providing the same quantities of N and P using commercial fertilizer are given for comparison. These cost figures do not include the cost of transporting sludge to the site nor the cost of storage. Details of costs derived during the study are presented in Tables 22 through 27. These tables also give the results by state or region for each of the three crops.

For this feasibility study, the cost values were based on three modes of application - injection, surface irrigation and truck-spreading of liquid sludge. It was found that, while some effort has been made to determine the cost of sludge application, most of the results reported do not show exactly what items were included in the cost values. The cost curves (Figures 5 to 13) used in this study were based on a study of sludge application in the San Francisco Bay Region (65).

TABLE 28. COST COMPARISONS FOR SLUDGE AND COMMERCIAL FERTILIZER

Application Mode	Units	Cotton				Sod				Biomass			
		N(S)[1]	Fertilizer[2]	P(S)[3]	Fertilizer[4]	N(S)[1]	Fertilizer[2]	P(S)[3]	Fertilizer[4]	N(S)[1]	Fertilizer[2]	P(S)[3]	Fertilizer[4]
Injection	$/DMT	137	198	200	1,455	62	198	258	1,455	89	198	95	1,455
	$/ha	1,229	71	1,034	226	1,364	160	1,156	197	1,197	97	746	342
Surface Irrigation	$/DMT	79	198	218	1,455	30	198	234	1,455	19	198	46	1,455
	$/ha	709	71	1,127	226	660	160	1,048	197	255	97	361	342
Truck Spreading	$/DMT	33	198	56	1,455	32	198	75	1,455	31	198	43	1,455
	$/ha	296	71	290	226	704	160	336	197	417	97	338	342

[1] N(S) = Nitrogen supplied using POTW sludge (does not include cost of sludge).

[2] Fertilizer = Nitrogen supplied using commercial fertilizer (custom application).

[3] P(S) = Phosphorus supplied using POTW sludge (does not include cost of sludge).

[4] Fertilizer = Phosphorus supplied using commercial fertilizer (custom application).

* The cost data presented for the sludge and the commercial fertilizer do not include the cost of transportation to the site and the cost of storage at the site.

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This study considered various regions and states. The primary impact on regional cost variations is due to the scale of sludge application. The Construction Cost Index (CCI) was used to adjust costs given in the literature to September 1979 (national average basis). The maximum regional cost variations in the CCI were about 7% for all cities (analysis conducted using March 1979 data). Most variations were less than 5%. The regional costs, therefore, were not computed using regional CCI values.

Any application of sludge to recover the N value involves the coincidental application of P and K as well. Some cost value could properly be claimed for the P and K recovery, especially in the case where NPK values as a whole are desired for the crop. Similarly, when applying sludge for the P value, there is a synonymous recovery of N and K. However, in both instances, the coincidental nutrient application is a benefit derived by using sewage sludge; no cost values are claimed. To illustrate the impact on the cost comparison when coincidental nutrient application is accounted for, the data on Table 29 were prepared. The fertilizer costs presented include a mixture of the required quantities of N and P for the crops. The value of K has not been included because of the relatively small sludge K content. Table 29 shows the following:

1. For all sludge application modes considered, application by injection is the most expensive with one exception. Application by surface irrigation is more expensive when applying sludge, based on P, to cotton.
2. Truck spreading is the cheapest application mode except for applying sludge, based on N, to sod or biomass. Application of sludge, based on N, to sod or biomass is cheaper when surface irrigation is used. Truck spreading appears to be cost competitive with custom application of the commercial fertilizer mixture.
3. Application of sludge, based on N or P, to biomass using surface irrigation or truck spreading is cheaper than custom application of a mixture of commercial N and P.

Transportation Costs

The most significant impact on regional costs variations will clearly be due to the transportation costs from the centers of sludge generation to the application sites. Transport costs were considered separately in this study. Transportation costs are presented in Figures 8 through 13 for 20, 40 and 60 mile distances and for liquid and cake shipping options. In most cases, cost differences were apparent among pipeline, barge, railroad and truck. Figures 11, 12 and 13 show transport costs for the cake option (pipeline not applicable to the transport of sludge cake). Trucking costs were largely nonvarying for the full range of production values. Trucking operations, however, are convenient for use at small plants where rail sidings are not feasible. As expected, there is little economy of scale in the case of trucking sludge cake. There is little economy of scale for rail transport at lower sludge quantities and distances. Rail and barge transport become more cost efficient at longer transport distances. Barge transport is of course

TABLE 29. COST COMPARISONS FOR SLUDGE** VERSUS COMMERCIAL FERTILIZER (FERTILIZER COSTS INCLUDE BOTH N AND P)

	Average total annual cost ($/ha)								
	Cotton			Sod			Biomass		
Application mode	N(S)	P(S)	Fertilizer *	N(S)	P(S)	Fertilizer*	N(S)	P(S)	Fertilizer*
Injection	1,229	1,034	290	1,364	1,156	350	1,197	746	432
Surface Irrigation	709	1,127	290	660	1,048	350	255	361	432
Truck spread	296	290	290	704	336	350	417	338	432

* All fertilizer costs are for custom application.
** Dry weight basis

not applicable to inland POTW's or inland application sites.

Cake transport implies a number of considerations which affect total system costs for NFCC application. If cake is being transported, dewatering costs at the POTW are probably higher than for other options. Cake may require re-slurrying at the application site for certain types of spreading.

Unit costs for rail and truck transport of liquid sludge are similar and fairly constant for all ranges presented. Pipeline costs are affected by pumping station requirements, but there is a significant economy of scale for increased capacities. Pipelines, however, require a fixed commitment over long periods of time and are very capital intensive. Rail transport is not labor intensive. Existing rail lines and facilities can be used with little or no adverse impact, and trains have a very low fuel consumption per metric ton-kilometer.

Pipelines and barges for liquid sludge transport and barges for sludge cake transport are clearly more cost efficient for most ranges of potential application, but are very limited by site, right of way, and on/off loading requirements.

Over the distances analyzed, the costs for transport of sludge cake averaged $27/DMT ($25/DT) and for liquid sludge, the costs for transport averaged $110/DMT ($100/DT) for both rail and truck, which are likely to be the most common options. The costs for sludge transport and application could be increased from two to seven orders of magnitude over the costs for application alone.

For the three sludge application modes investigated, the costs for applying the sludge, based on N, range from 41% less than the cost of custom application of a commercial fertilizer mixture to 324% greater than the cost of custom application. When transport costs are added to the sludge application costs, the total cost for the sludge ceases to be cost competitive with custom application, even for the cheaper application modes. For example, in the case of N application, for biomass production using surface irrigation (Table 29), the cost for sludge application, on a $/ha basis, is 41% less than the cost for custom application ($/ha) of a mixture of N and P commercial fertilizers. When the transport cost ($/DMT) for sludge cake is added to the application cost of the sludge, the cost of the sludge is increased by 142% (see Table 28). This 142% increase in the sludge cost, on a $/DMT basis, increases the sludge cost, on a $/ha basis, from 41% less than the cost for custom application to 43% greater than the cost for custom application of a fertilizer mixture. This shows that adding transport cost to the application cost would put most options considered far out of the range of possible consideration (based on costs alone). The transport costs for commercial fertilizer are not that significant, because the seller of the product usually locates near the centers of use.

Clearly, a great many permutations are possible among transport modes, application types and rates and crop types. A detailed analysis of the many alternative combinations is beyond the scope of this study. The data and information, however, are presented to permit a more detailed examination.

The application rates for sludge affect costs. Where sludge quantities are small, e.g., P injection application to sod in the Mississippi case, (see Table 25), costs are high when compared to costs for application of commercial fertilizer and when compared to other states or regions where application rates are higher. In general, the low sludge application rates result in an unfair comparison because equipment and other capital costs are annualized with a poor economy of scale.

Clearly, if sewage sludge is to compete with commercial products for supplying the necessary N and P for crop production, the costs for operation will have to be borne by the municipality generating the sludge. If the municipality would transport the sludge to the site of application and provide the application equipment, then the sludge would be a sought after product when costs for this product are compared with the costs for the commercial product.

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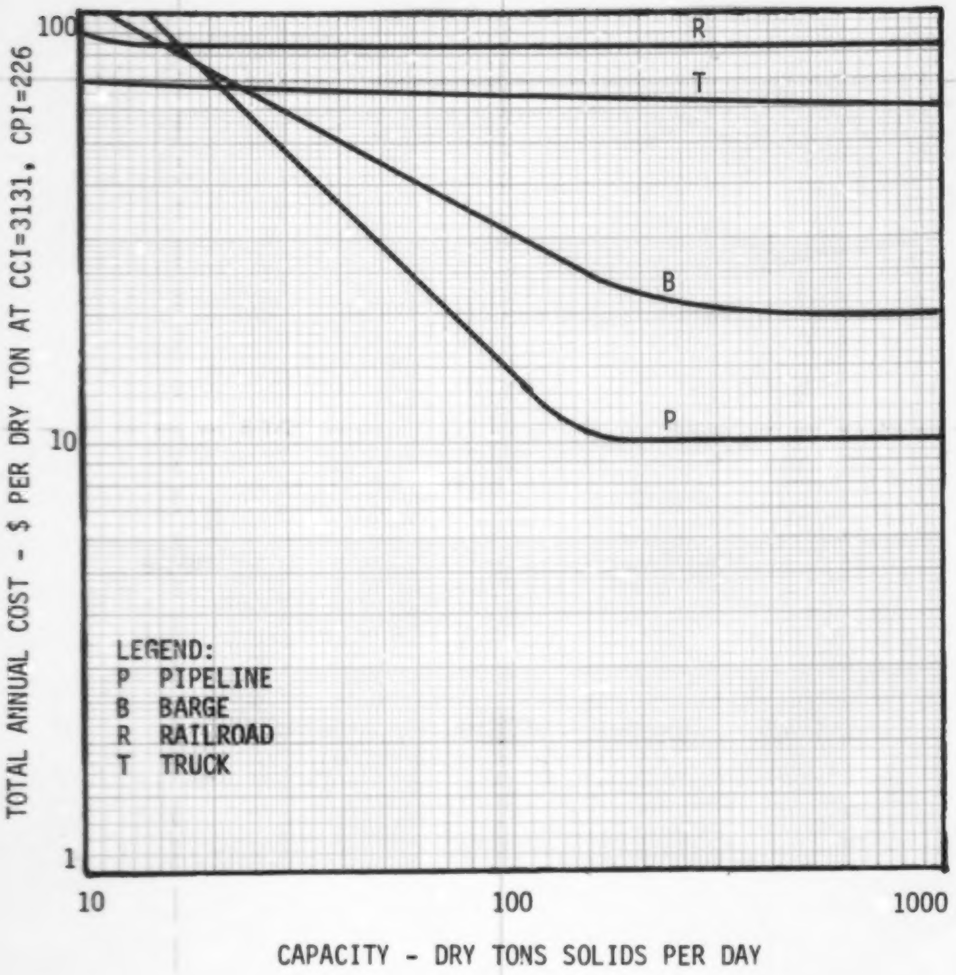

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CPI - CONSUMER PRICE INDEX = 226, OCTOBER 1979
DRY TONS (SHORT) x 0.9072 = DRY TONS (METRIC)

Figure 8. Costs of liquid sludge transport - 20 miles.

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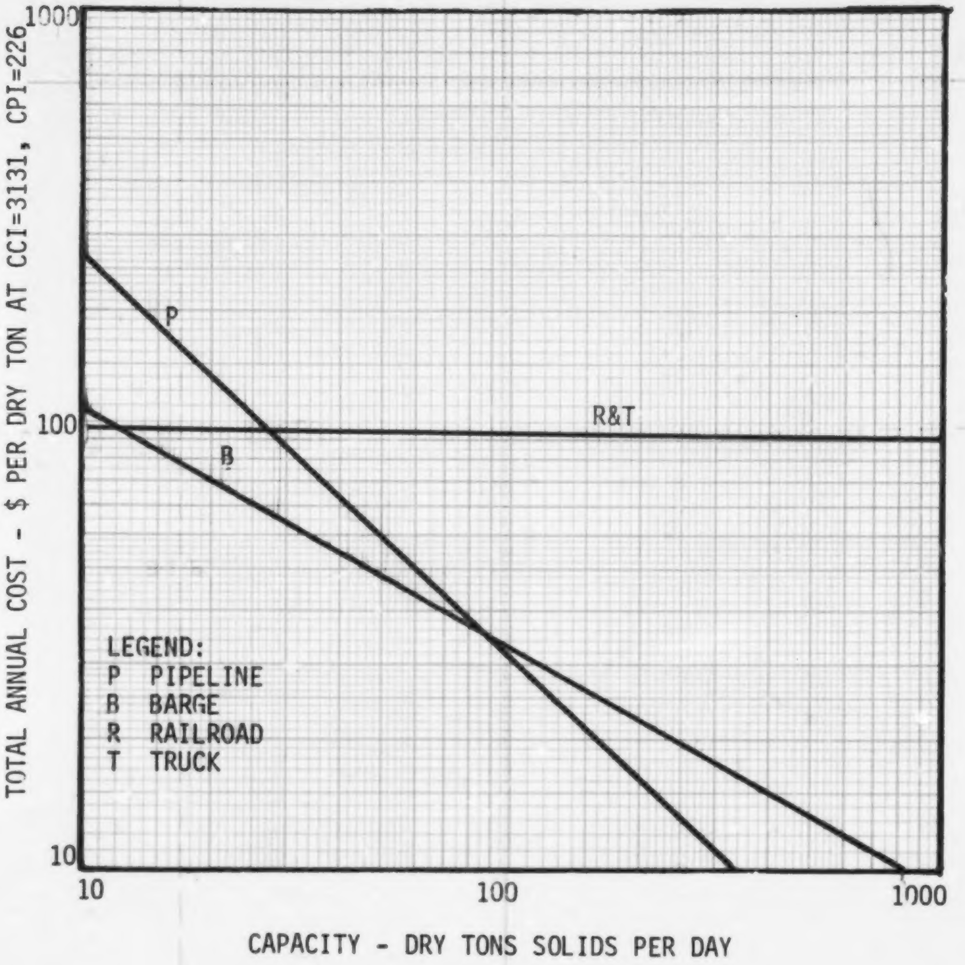

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Figure 9. Costs of liquid sludge transport - 40 miles.

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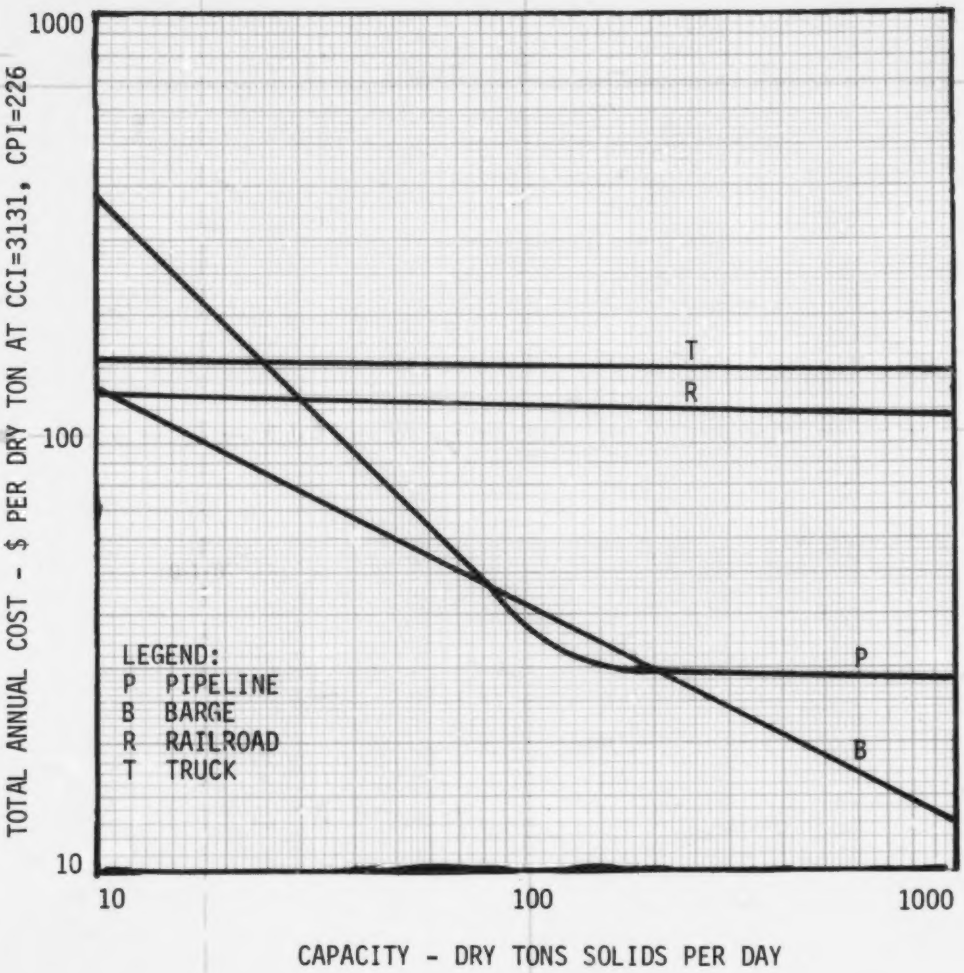

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Figure 10. Costs of liquid sludge transport - 60 miles.

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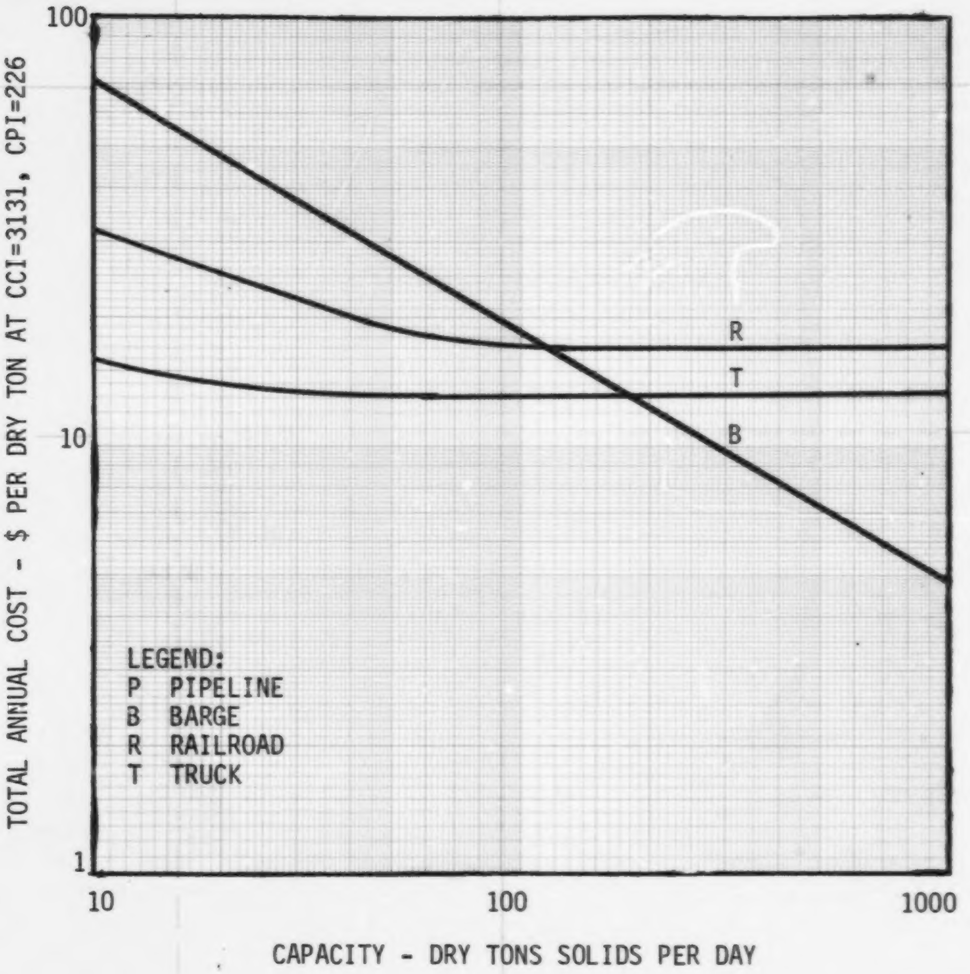

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Figure 11. Costs of sludge cake transport - 20 miles.

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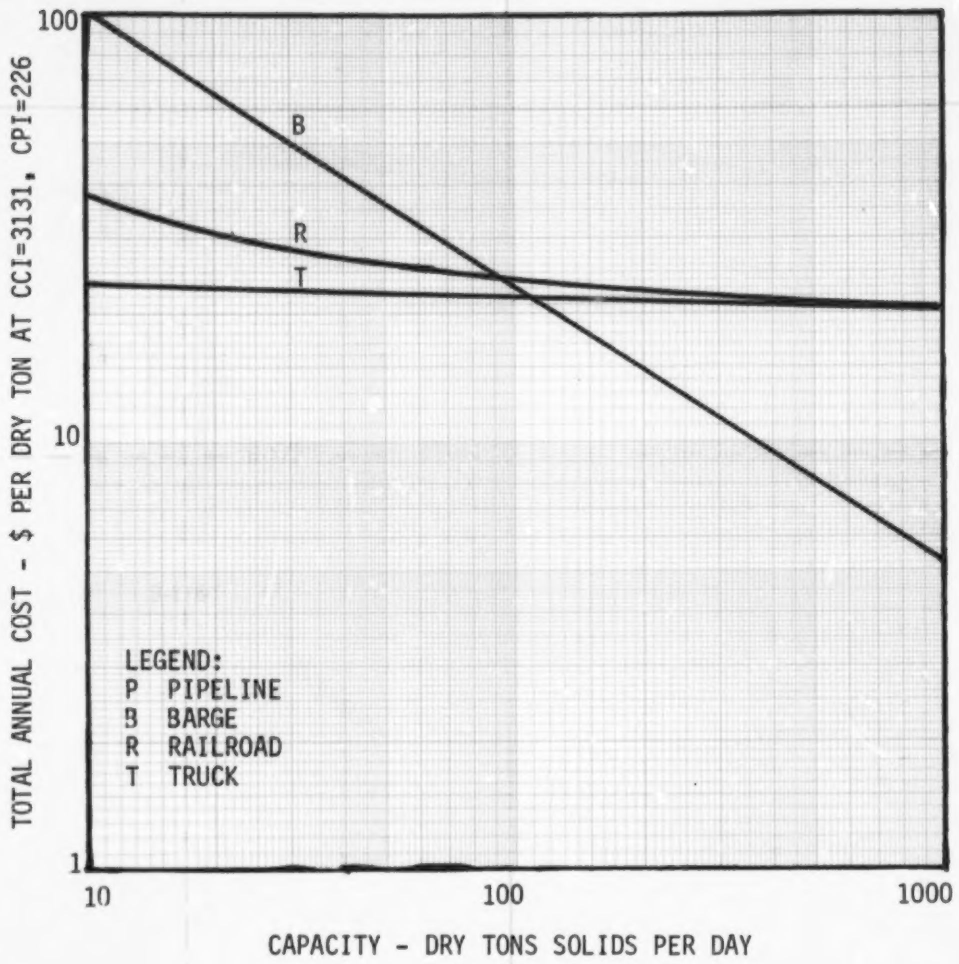

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Figure 12. Costs of sludge cake transport - 40 miles.

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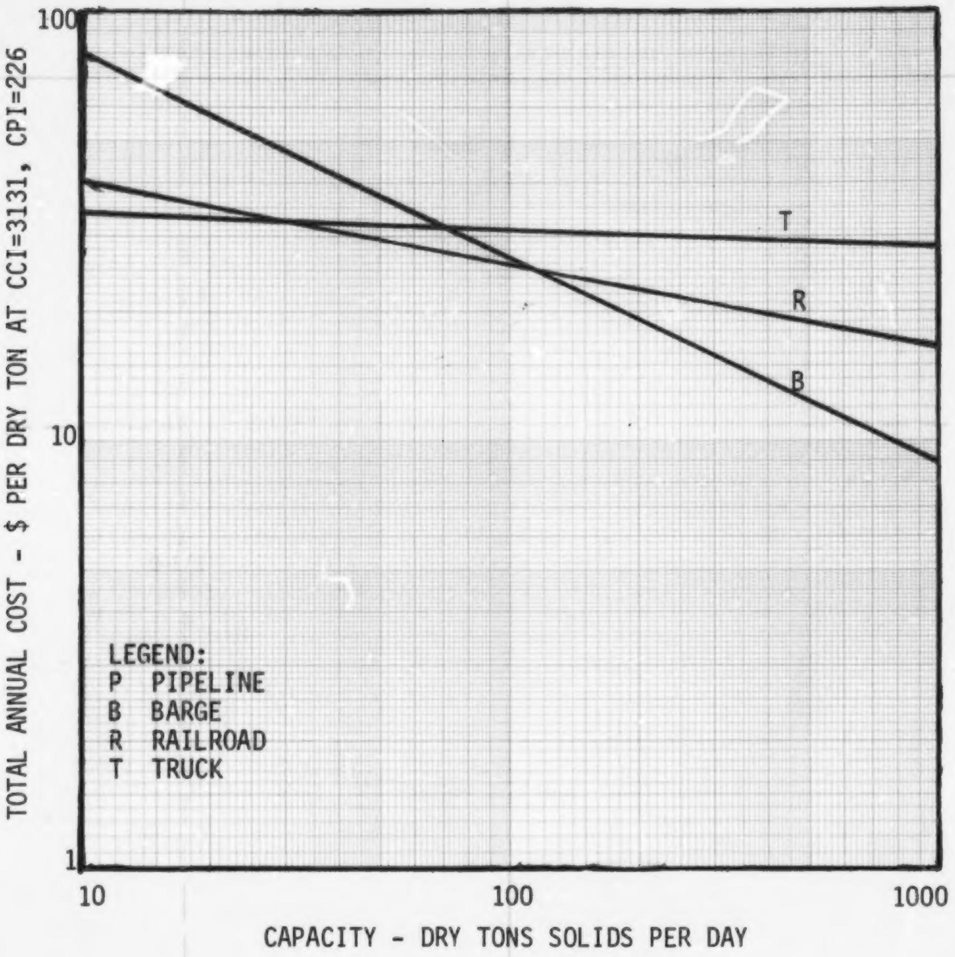

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DRY TONS (SHORT) x 0.9072 = DRY TONS (METRIC)

Figure 13. Costs of sludge cake transport - 60 miles.

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